VOLUME 84 NO. PO6
DECEMBER 1958

JOURNAL of the

Power Division

PROCEEDINGS OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS

BASIC REQUIREMENTS FOR MANUSCRIPTS

This Journal represents an effort by the Society to deliver information to the reader with the greatest possible speed. To this end the material herein has none of the usual editing required in more formal publications.

Original papers and discussions of current papers should be submitted to the Manager of Technical Publications, ASCE. Authors should indicate the technical division to which the paper should be referred. The final date on which a discussion should reach the Society is given as a footnote with each paper. Those who are planning to submit material will expedite the review and publication procedures by complying with the following basic requirements:

1. Titles should have a length not exceeding 50 characters and spaces.

2. A 50-word summary should accompany the paper.

3. The manuscript (a ribbon copy and two copies) should be double-spaced on one side of 8½-in. by 11-in. paper. Papers that were originally prepared for oral presentation must be rewritten into the third person before being submitted.

4. The author's full name, Society membership grade, and footnote reference stating present employment should appear on the first page of the paper.

5. Mathematics are reproduced directly from the copy that is submitted. Because of this, it is necessary that capital letters be drawn, in black ink, ⅛-in. high (with all other symbols and characters in the proportions dictated by standard drafting practice) and that no line of mathematics be longer than 6½-in. Ribbon copies of typed equations may be used but they will be proportionately smaller on the printed version.

6. Tables should be typed (ribbon copies) on one side of 8½-in. by 11-in. paper with a 6½-in. by 10½-in. invisible frame. Small tables should be grouped within this frame. Specific reference and explanation should be made in the text for each table.

7. Illustrations should be drawn in black ink on one side of 8½-in. by 11-in. paper within an invisible frame that measures 6½-in. by 10½-in.; the caption should also be included within the frame. Because illustrations will be reduced to 69% of the original size, the capital letters should be ⅛-in. high. Photographs should be submitted as glossy prints in a size that is less than 6½-in. by 10½-in. Explanations and descriptions should be made within the text for each illustration.

8. Papers should average about 12,000 words in length and should be no longer than 18,000 words. As an approximation, each full page of typed text, table, or illustration is the equivalent of 300 words.

Further information concerning the preparation of technical papers is contained in the "Technical Publications Handbook" which can be obtained from the Society.

This Journal is published bi-monthly by the American Society of Civil Engineers. Publication office is at 2500 South State Street, Ann Arbor, Michigan. Editorial and General Offices are at 33 West 39 Street, New York 18, New York. $4.00 of a member's dues are applied as a subscription to this Journal. Second-class postage paid at Ann Arbor, Michigan.

SM,PO,SA.

Journal of the
POWER DIVISION
Proceedings of the American Society of Civil Engineers

CONTENTS

December, 1958

Papers

Journal of the
POWER DIVISION
Proceedings of the American Society of Civil Engineers

LAS MOROCHAS GAS TURBINE POWER PLANT[a]

A. J. Michael,[1] A. M. ASCE
(Proc. Paper 1886)

The generating capacity of the Las Morochas Power Plant is being increased by the addition of three gas turbine driven generators. This additional generating capacity is required to meet the increased demand for electric power for the oil drilling operations in the Lake Maracaibo area of Compañia Shell de Venezuela, Ltd. The Las Morochas Power Plant and the plant at Pueblo Viejo (see Fig. 3), together with their interconnecting and transmission circuits, form the Bolivar Coast Power System.

As originally conceived the system was to consist of a single power plant at Pueblo Viejo, having 20,000 kw of installed capacity in steam turbine driven generators. The energy produced was to be transmitted north and south on a pair of 33 kv transmission circuits in each direction, an airline distance of less than 30 km in each direction.

Subsequent additions to the transmission system have increased these airline distances to some 40 km southward and over 50 km northward.

Following the extension of the 33 kv transmission circuits, additional generating capacity was installed at Pueblo Viejo, so that the plant capacity is now 40,000 kw. The problem of transmitting this capacity through the 33 kv system to the distances now involved brought about a solution including the addition to the system of a second power plant at Las Morochas.

This plant had been operating as an isolated station with an installed capacity of 15,000 kw, furnished by four low pressure steam turbine driven generators. Upon integration into the system, the capacity was increased to 45,000 kw by the addition of two higher pressure steam turbine driven generators of 15,000 kw rated capacity each. These new generators are housed in a new building completed and put in service in 1955.

Simultaneously with this addition, 69 kv transmission circuits were installed to interconnect Pueblo Viejo and Las Morochas. The 33 kv circuits already in service were divided and rearranged so that each power plant fed north and south, reducing the airline distance to the most remote northerly

Note: Discussion open until May 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1886 is part of the copyrighted Journal of the Power Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. PO 6, December, 1958.

a. Presented at the October, 1958 ASCE Convention, New York, N. Y.
1. Structural Engr., The J. G. White Eng. Corp., New York, N. Y.
N. Y.

point to about 25 km. The portion of the 33 kv system south of Pueblo Viejo was unaffected. Circuits to the east were also provided for.

The next, and present, step is the addition of 60,000 kw to the capacity of the Las Morochas plant, the conversion of the 69 kv system to 115 kv and the extension of this system. Three gas turbine driven generators, each of 20,000 kw rated capacity, are being installed in an extension of the 1955 building. These units are among the largest gas turbines presently manufactured, and Las Morochas is one of the largest gas turbine installations ever undertaken at one time.

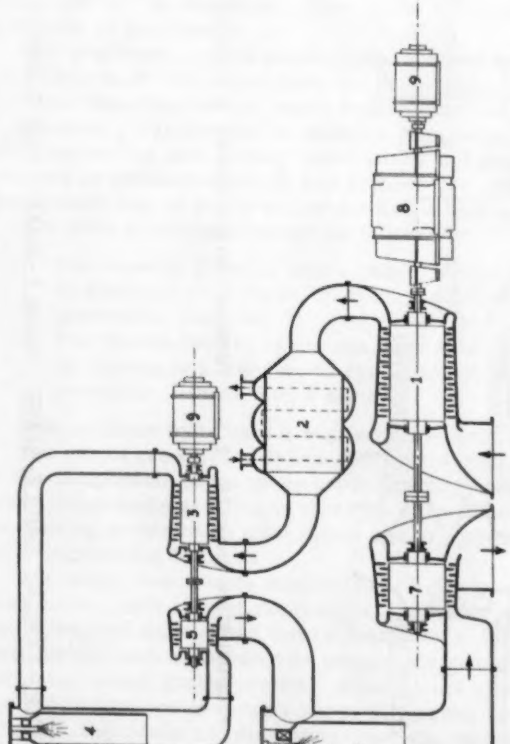
Although modern type gas turbines have been used for commercial power generation for about thirty years, it is only during the last few years that their use has become more widespread. The further development of design, materials and manufacturing technique will undoubtedly result in these units being built with a much larger capacity than now, and this, coupled with their advantages for certain operating and site conditions, indicates that civil engineers in the field of power generation will be dealing with them regularly.

A civil engineer must be familiar with all of the general, and many of the detailed features of all components of a project in order to perform his functions efficiently. Since the use of gas turbines in power plants is not as widespread as the use of other prime movers, a brief description of these turbines is appropriate. Fig. 1 shows, in outline form, the operation of a two-stage, intercooled, two-shaft gas turbine. Air enters the low pressure turbine compressor at (1), is compressed, passes through the intercooler (2), is compressed again in the high pressure compressor (3), and is mixed with fuel and burned in the high pressure combustion chamber (4). The heated and expanding mixture of exhaust gas and air drives the high pressure turbine (5), and exhausts to the low pressure combustion chamber (6), where the burning of additional fuel further heats the mixture. This expanding mixture then passes to and drives the low pressure turbine (7). It can be noted that the generator (8) is connected to the low pressure turbine only.

Fig. 2 shows in outline form a single-stage, single-shaft gas turbine. This type of machine is similar to the two-stage, two-shaft machine except that the intercooler and the high pressure compressor and turbine cycle are not included. In neither of the machines outlined is a heat exchanger (regenerative cycle) shown. A regenerative cycle (preheating the air entering the combustion chamber by passing it through a heat exchanger with the exhaust gases) results in higher efficiency, but raises certain operating problems. A discussion of these operating problems, together with more detailed descriptions of gas turbine technology are not within the scope of this paper.

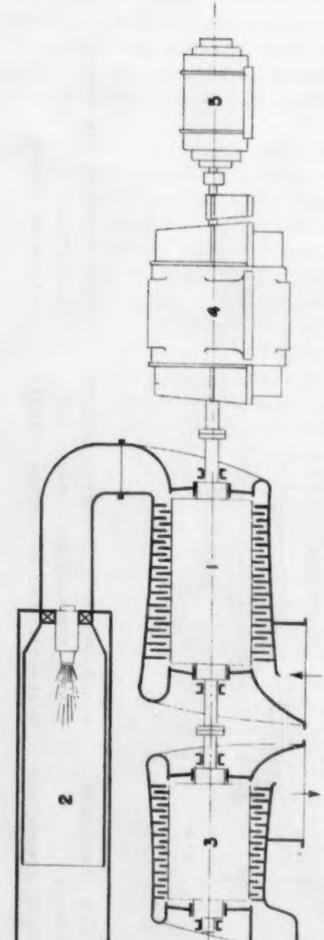
Once the questions of reliability and suitability are satisfactorily answered, the decision to use any particular combination of materials, machines and systems in the installation of a power generating station is properly based on economics. But since the economics of power generation is a very complicated affair and considerations peculiar to each individual station have a great weight, the brief resume of the reasons for deciding to use gas turbines at the Las Morochas Power Plant can only apply to this installation or one very similar.

The total cost of electric power is composed of two principal parts: (1) capital cost, and (2) operating cost, including personnel, maintenance and fuel. The capital cost of gas turbine installations is generally less than that of steam turbine installations due to the elimination of the steam generator and its auxiliaries. The personnel costs for a modern power plant, either gas



1 = LOW-PRESSURE COMPRESSOR
2 = AIR INTERCOOLER
3 = HIGH-PRESSURE COMPRESSOR
4 = HIGH-PRESSURE COMBUSTION CHAMBER
5 = HIGH-PRESSURE GAS TURBINE
6 = LOW-PRESSURE COMBUSTION CHAMBER
7 = LOW-PRESSURE GAS TURBINE
8 = GENERATOR
9 = STARTING MOTORS

FIG.1.—TYPICAL TWO-STAGE, TWO-SHAFT GAS TURBINE



1 = COMPRESSOR 2 = COMBUSTION CHAMBER 3 = GAS TURBINE 4 = GENERATOR 5 = STARTING MCTOR

FIG. 2.—TYPICAL SINGLE-STAGE, SINGLE-SHAFT GAS TURBINE

turbine or steam turbine, are approximately equal. There is not as yet sufficient operating experience to form an accurate estimate of maintenance costs of gas turbines of this capacity. However, present experience does indicate that even if the maintenance of gas turbines must be performed more frequently than for steam turbines, this will be offset by the elimination of maintenance of the steam generator and its auxiliaries.

In most circumstances the BTU per kilowatt would be an important factor in comparing the operating costs of the two types of installation. The principal fuel in either case at this installation would be natural gas, which is a by-product of the oil production operations. This fuel cost is therefore very small and has no significant effect on the economic determination between the two types of installation.

The condenser cooling water intake screens and channel and the discharge channel built in 1955 were sized for the addition of one 15,000 kw steam turbine. Since the cooling water requirements of gas turbines are comparatively small, it is possible to install a generating capacity of 60,000 kw without constructing new cooling water intake and discharge channels. For the reasons as outlined above, it was decided that gas turbines were the most economical type of prime mover for use in this installation.

The units to be installed are as follows:

1. One General Electric single-stage, single-shaft gas turbine, coupled by gearing to a 3 phase, 60 cycle, 13,800 volt, 3,600 rpm air-cooled generator. (Unit No. 7)
2. Two Brown Boveri, two-stage, two-shaft, gas turbines, each coupled by gearing to a 3 phase, 60 cycle, 13,800 volt, 3,600 rpm air-cooled generator. (Units Nos. 8 and 9)

None of these units uses a regenerative cycle.

The use of gas turbine driven generators resulted in elimination of certain of the components of the more usual type of power plant and the inclusion of other components peculiar to this type of installation. This presented several interesting problems in plant layout and arrangement and in the design of the civil engineering features.

The major components eliminated are (1) the steam generator and its auxiliaries, such as heat exchangers, feedwater pumps, feedwater treating facilities, and induced and forced draft plants; (2) the steam condenser and its auxiliaries, such as condensate pumps, air ejectors and surge tanks; and (3) the entire steam piping system. Although not eliminated, the amount of cooling water required is greatly reduced, thereby reducing the size of the intake screens, the intake and discharge channels, and the cooling water piping system.

The major components added are (1) the air intake structure with its filters and silencers and (2), at this installation, the fuel gas compressors. The design of the exhaust gas ductwork and stack is made more involved because of the large volume of high temperature exhaust gas and the need for silencers. Due to the high operating temperatures of these turbines, ventilation must be more extensive than usual.

Each of these items is discussed in greater detail below, first as they affect plant layout and then as they affect the detailed civil engineering design.

Plant Layout

The Las Morochas Power Plant is located on the east shore of Lake Maracaibo, Venezuela about 40 miles southeast of Maracaibo on a very flat, low-lying site about 31 acres in extent with 1,300 feet of frontage on the lake. Accommodated on this site are the Power Plant proper, the 34.5 kv Substation, the 69 kv Substation and housing for supervisory personnel. (See Fig. 3) The building has its long axis running generally north-south (see Fig. 4), with the steam generators and auxiliaries on the west side and the transmission substations on the east. It is a steel frame structure covered by corrugated asbestos-cement siding and roofing. (See Fig. 5)

The basic function of all thermal power plants—the conversion of heat energy to electrical energy—is the same. All of the major equipment, their auxiliaries and the structures that support and house them must be arranged so that this basic function, from fuel supply to waste disposal, is carried out in the most economical manner at the site selected. The discussion of plant layout in general follows the fuel through the plant and the electrical energy out.

Liquid fuel is stored and handled on the westerly portion of the site. As mentioned, the principal fuel at Las Morochas is natural gas from the oil wells. Diesel oil for the gas turbines (delivered to the site by barge) and fuel oil for the steam generators are for standby use only. Since these fuels are comparatively easy to handle, no extensive storage or handling facilities are required. Only a few oil storage tanks together with their transfer pumps are provided; 11,000 barrels of fuel oil and 11,500 barrels of diesel oil are stored on the site. Safety valves and vents in the fuel gas piping system are exhausted to a flare located north of the power plant.

Since the pressure of the natural gas is not high enough for turbine operation, two motor driven reciprocating gas compressors are being installed. Because of the highly flammable character of the fuel gas, these compressors are located in the west aisle and separated from the rest of the plant by concrete block walls. (See Fig. 6) Louvers replace the exterior siding in this area (see Fig. 5) and a battery of fans is installed in the block walls to insure that escaped fuel gas will be exhausted to the atmosphere.

Air intake structures are provided on the west side of the building to filter and funnel to the turbines the large volume of air required; 268,000 SCFM are required for each of the Brown Boveri machines, and 323,000 SCFM are required for the General Electric machine. Air passes through the filters at about 400 feet per minute and its velocity is increased due to the shape of the structure so that, at the compressor inlet, the velocity is approximately 88 mph for the General Electric machine and 51 mph for the Brown Boveri machines. Due to the objectionable level of noise propagated by the compressors, it was necessary to install silencers. Because of the different compressor characteristics of the two types of units, sound stream silencers were installed for Units Nos. 8 and 9, and splitter vane silencers were installed for Unit No. 7. The use of silencers will reduce the noise level for each machine so that it will not be objectionable in the personnel housing area at a distance of 500 feet from the screens.

One of the prime considerations was fitting this installation into an extension of the existing 1955 building, while maintaining the elevation of the crane rail and the operating floor as well as the building cross-section. (See Fig. 6) The building is arranged with an aisle 25 feet wide on either side of

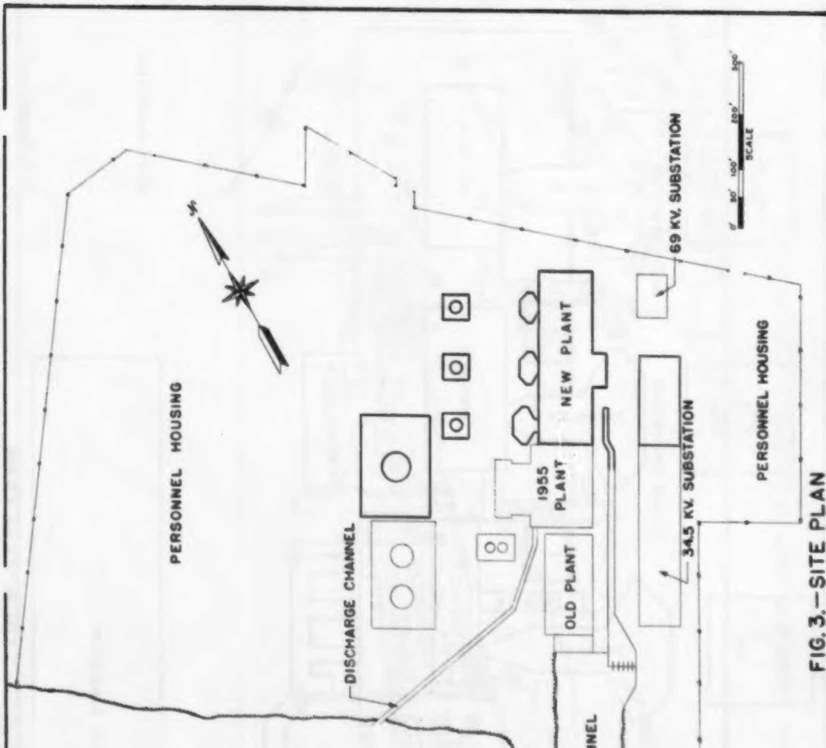


FIG. 3.—SITE PLAN

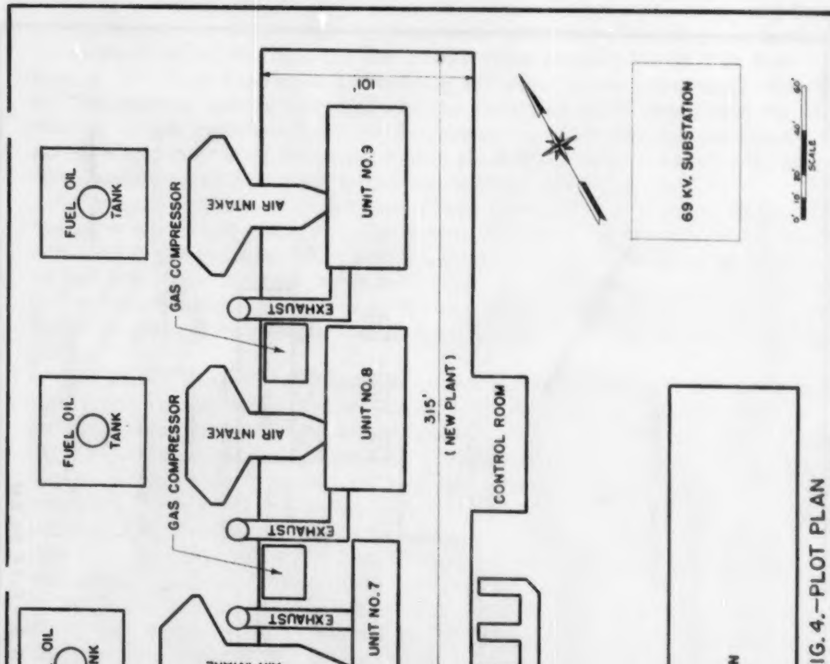


FIG. 4.–PLOT PLAN

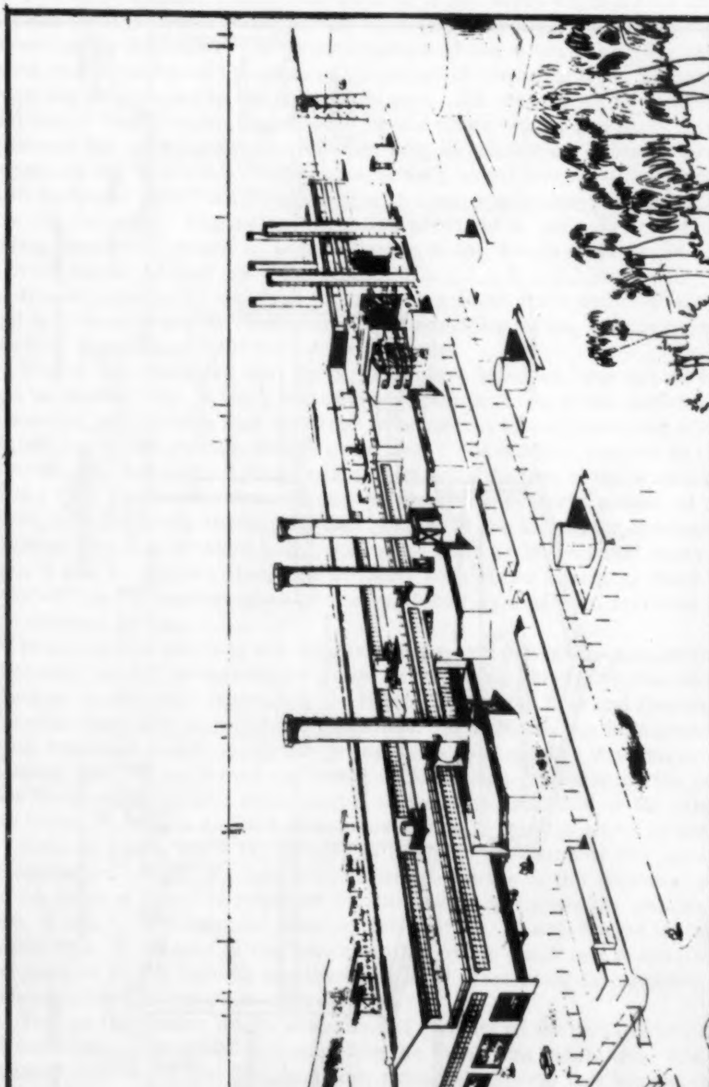


FIG.5.-LAS MOROCHAS POWER PLANT — LOOKING SOUTHEAST

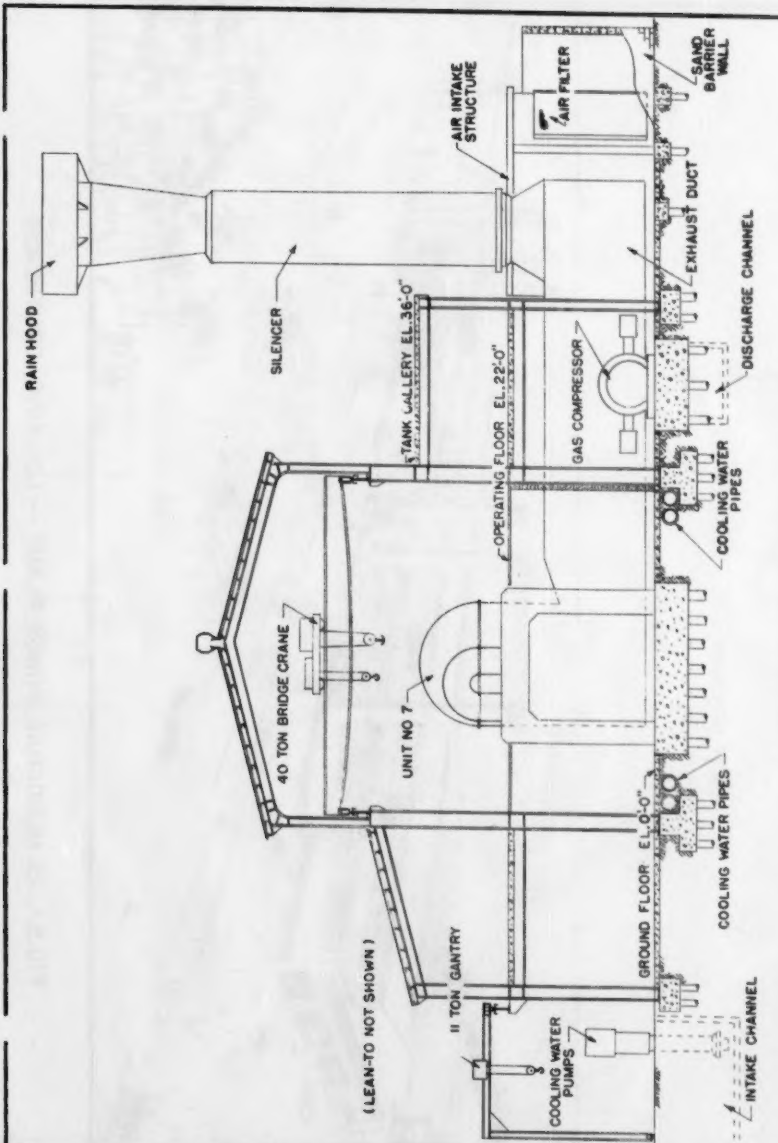


FIG.6.-CROSS-SECTION LOOKING SOUTH

the turbine aisle which is 51 feet wide. The westerly aisle is generally used for mechanical equipment while the easterly aisle is generally used for electrical equipment. Each side aisle is a two-story rigid frame and the roof over the turbine aisle is supported by a single-span, single-story rigid frame connected to the tops of the inner columns of the side aisles. Stability in the north-south direction is achieved by means of cross-bracing in about every third bay, connected to the column flanges. All steel work is shop-riveted and major field connections welded, while filler beams and girts are bolted. Although the building is over 450 feet long no expansion joints in the steel structure are provided. The comparatively small temperature fluctuation—both daily and seasonally—together with local experience, indicates that they are not required. Expansion joints are provided in the corrugated asbestos siding since this material, being exposed to the direct sunlight, is subject to a much larger temperature variation.

It was possible to maintain the operating floor and crane rail elevations and still have space for installation and servicing of the machines, since the vertical dimensions of the plant were ample.

Fitting the machines into the plant in plan, however, was not as easy. As can be seen in Fig. 4, each machine occupies an area in the turbine aisle somewhat larger than that required to accommodate a preferred standard 60,000 kw steam turbine driven generator. The outdoor portion of the air intake structure covers a plan area almost equal to that of the steam generators in the 1955 plant. North-south access along the westerly aisles, at grade level, is completely blocked by that portion of the air intake connecting to the turbine, and also blocked at the operating floor by the exhaust ducts of Units Nos. 8 and 9. Access along the westerly side of the operating floor (Elevation + 22'-0") in the turbine aisle is accomplished by means of inverted stiles at the exhaust ducts.

In an attempt to clear the westerly aisle, consideration was given to constructing the air intakes below grade in this area. However, the additional changes in direction increased the resistance to air flow and thereby reduced the efficiency and output of the machines. In addition, the high ground water level required rather elaborate precautions to eliminate the danger of water seeping into the air intake and being sucked into and damaging the compressor. For these reasons, and since ample access was available on the other side of the turbines, it was decided to construct the air intakes above grade.

Exhaust gases leave the turbine at a design pressure of 100 psf and a temperature of 850° F. Due to the characteristics of the machine, silencing of the exhaust gases is required for Unit No. 7 and probably required for Units Nos. 8 and 9. The exhaust silencer for Unit No. 7, which is of the cross-baffle type, is located in the lower section of the stack and prevents the noise propagated by the turbine (combustion, etc.) from being transmitted with the exhaust gases to the atmosphere.

The cooling water intake screens and channel of the 1955 power plant were of sufficient capacity to accommodate the three new machines. The intake channel side walls and slab had been extended several feet beyond the end wall and constructed with keys and dowels for future extensions. Advantage was taken of these provisions to extend the intake channel far enough to construct the pump bays for the cooling water pumps. Because of the relatively small amount of cooling water required for each machine, the pumps for all three are located near Unit No. 7 and 24-inch diameter pipes located under the ground floor slab are used instead of extending the channel to the other units. The discharge channel, which was prepared for extension similarly to

the intake, was extended only far enough to build a new end wall accommodating the discharge ends of the cooling water pipes. The cooling water circulating pumps as well as the station service water pumps are serviced by a 10-ton capacity gantry crane. One leg of this crane runs on a rail supported at grade level and the other on a rail bracketed from the building columns about 25 feet above grade. This gantry runway was extended to service the new pumps.

Ventilation of the 1955 building was accomplished by means of a gravity type, roof-ridge mounted ventilator with a 24-inch throat opening, together with continuous windows at the grade level and the operating floor level. The new extension required additional ventilation due to the higher operating temperature of these turbines. The ridge ventilator is still to have a 24-inch throat opening in order to maintain the outside continuity of appearance. Increased capacity is accomplished by adding a row of windows on both sides of the building above the crane rails, and installing windows on the west side at the operating floor level. (See Fig. 5)

All of the waste products of combustion of the fuels used are gaseous and therefore liquid or solid waste product handling systems are not required.

The transmission substation (34.5 kv), which is located to the east of the intake channel and access road, receives power from the generators at generated voltage, steps up the voltage and the power then enters the transmission system from the 34.5 kv buses. A certain portion of the power is stepped down and returns to the plant to operate auxiliaries at 2,400, 440, 220 and 110 volts. Cable trenches, constructed below grade connect this substation to the power plant. This substation was extended to the north to accommodate the new generators.

The control room, from which the generators, the substation and other substations in the transmission system are controlled, occupies an area approximately 40 feet square on the operating floor in the east side of the building. This square area, part of which had to be housed in a leanto, was required to accommodate all the.boards and panels in a U shape for best operation.

Civil Engineering Design

Dutch Cone Penetration Tests taken for the 1955 building indicated that there are two strata of sufficient bearing capacity to sustain the loads expected from a power plant. The first, at a depth of approximately 6 feet below grade, is a layer of fine sand about 2 feet thick and has a design bearing capacity of 2,500 psf. The second, at approximately 25 feet below grade, is a mixture of hard clay and gravel and has a design bearing capacity of 60,000 psf. It was decided to support the main buinding columns and major equipment on piles, and this system was continued for the present extension. The piles, which are cast-in-place concrete piles, have a design capacity of 30 tons each. Pile load tests made recently confirm this capacity.

As mentioned, the site is low-lying and relatively flat. This required the use of cut-off ditches to intercept the surface drainage that normally flowed across the site to the lake. Because of the low elevation and the long distance to the lake, a collecting basin was constructed west of the 34.5 kv substation and pumps installed to discharge the drainage water to the lake. This collecting basin is constructed as two chambers connected at the bottom, so that the dividing wall acts as an oil separator in case of a major oil leak in the substation.

The entire design of the air intake structure is predicated on the elimination of solid particles from the air entering the turbine compressor, since even minute particles would damage the blading. Oil bath filters, mounted in the upstream end of the air intakes, are better than 99% efficient for all particles 10 microns or larger in diameter. Further protection is provided by a concrete block wall constructed in front of the filters to prevent excessive amounts of sand being blown against the filters.

Access to the interior of the air intake structure is by means of a concrete vestibule or air lock. Both of the doors in the vestibule are gasketed and held firmly against the gaskets by means of levered bars. The interior surfaces are to be treated with a surface hardener and then painted with a smooth, hard surface enamel to prevent concrete dust from entering the machine.

The walls, floor and roof of the air intake structures for the Brown Boveri machines are designed for a uniformly distributed load of 400 psf in either direction to allow for pressures due to possible surging of the gas turbine compressor. Any loading in excess of this amount is taken care of by a row of pressure-relief windows which are pivoted about a horizontal support and can open in either direction.

Excluding pile caps, but including foundation beams, there are 360 cubic yards of concrete and 50 tons of reinforcing steel in each of the air intake structures for the Brown Boveri units and 330 cubic yards of concrete and 30 tons of reinforcing steel for the General Electric unit.

The foundation superstructure for each Brown Boveri machine is a rigid frame steel structure designed so that the natural frequency of vibration of the entire structure and of each component part is less than the vibration frequency induced by the machine operating at rated speed. The General Electric machine is supported on a massive concrete foundation designed to dampen vibrations.

This latter foundation superstructure consists of 12 columns with connecting beams, forming two 6-legged rigid frames in the north-south direction and six 2-legged rigid frames in the east-west direction. The total equipment load to be supported by the foundation is 270 tons. The longitudinal, transverse, short-circuit and torque live loads are, for design purposes, percentages of the equipment load, which are the same as for steam turbine driven generators.

Due to the elimination of the condenser, steam and condensate piping and auxiliaries it was believed that the design of the turbine generator foundation would be greatly simplified. The large intake and exhaust ducts, however, presented an even more difficult clearance problem than a condenser. The solution of this problem required a compromise between the mechanical and structural designers concerning the ideal size and shape of these ducts and the ideal size and locations of foundation beams and columns in this area.

All three foundation superstructures are supported on mats and are completely separated from the building steelwork and all other foundations. Including the foundation mat, there are 72 piles, 650 cubic yards of concrete and 65 tons of reinforcing steel in the foundation for Unit No. 7, while there are 58 piles, 430 cubic yards of concrete, 6 tons of reinforcing steel and 84 tons of structural steel in each of the other foundations.

The exhaust ducts and stacks for Units Nos. 8 and 9 are designed and fabricated in Europe. This discussion of problems encountered in the design of the exhaust ducts and stacks is therefore limited to that for Unit No. 7. The turbine exhaust flange, as the machine reaches operating temperature, moves

0.75 inches north and the same distance downward. The manufacturer limited the load on this flange to 10,000 lbs. direct load and 10,000 ft.-lbs. moment. The size of the exhaust duct is so large compared to the diameter of the stack that, if the usual type of breeching connection were made, it would be necessary to install very heavy, uneconomical reinforcing on the stack. The velocity of the exhaust gases and the clearance problems inside the building both made it impossible to change the cross-sectional shape of the exhaust duct to reduce this reinforcing. It was therefore decided to support the stack at Elevation +22'-0", and have the exhaust duct enter the stack from the bottom. This had the added advantage of providing anchorages at either end of the exhaust duct system at approximately the same elevation, thereby largely eliminating one plane of differential expansion. The exhaust duct system as finally designed consists of three sections, (1) the elbow under the turbine flange, (2) the center section, and (3) the elbow under the stack. (See Figs. 7 and 8) Section 1 is bolted to the turbine flange, supported on constant load spring hangers and guided by two-directional roller nests to permit it to follow the movement of the turbine flange but to prevent the transmission of moments or shears to the flange. Section 3 is bolted to the stack and guided by two-directional roller nests to allow only vertical motion and its own growth and to prevent rotation. This support system for the elbow sections maintains their flanges parallel to each other. The center section is supported by constant load spring hangers and connected to the elbow sections by bellows type expansion joints. This permits the center section to move in the horizontal and vertical directions to follow the movements of the elbow sections. Axial expansion is taken up by compressing the expansion joints and angular deflection of these joints allows the motion of the center section. The constant load spring hangers prevent the transmission of excessive shearing forces across the joints. To minimize the angular deflection in the expansion joints, the centerline of Section 1 is set 3/8 inch south of the centerline of Section 3, thereby cocking the center section. When Section 1 expands northward 3/4 inch the center section swings through a neutral position and comes to rest in the hot position cocked 3/8 inch the other way.

The entire Las Morochas Power Plant extension requires the use of 1,250 tons of structural steel, 6,000 cubic yards of concrete, 400 tons of reinforcing steel and 600 piles.

All equipment and material, with few exceptions, have been purchased in Europe. Unit No. 7 and some auxiliaries and a small amount of structural steel have been purchased in the United States. Concrete is being procured locally.

Construction is to be accomplished under three contracts, one for all civil engineering works, one for the installation of Units Nos. 7 and 8, and a third for the installation of Unit No. 9. Present estimates indicate that the total cost of the installation will be on the order of $12,000,000.

Messrs. R. Boers, Senior Electrical Engineer, and P. A. van Gent, Project Engineer, are in charge of this project for the owner, Compañia Shell de Venezuela, Ltd. The design and supervision of construction are being performed by The J. G. White Engineering Corporation, with the civil engineering features under the supervision of Messrs. M. P. Aillery, Chief Structural Engineer and A. J. Michael, Structural Engineer.

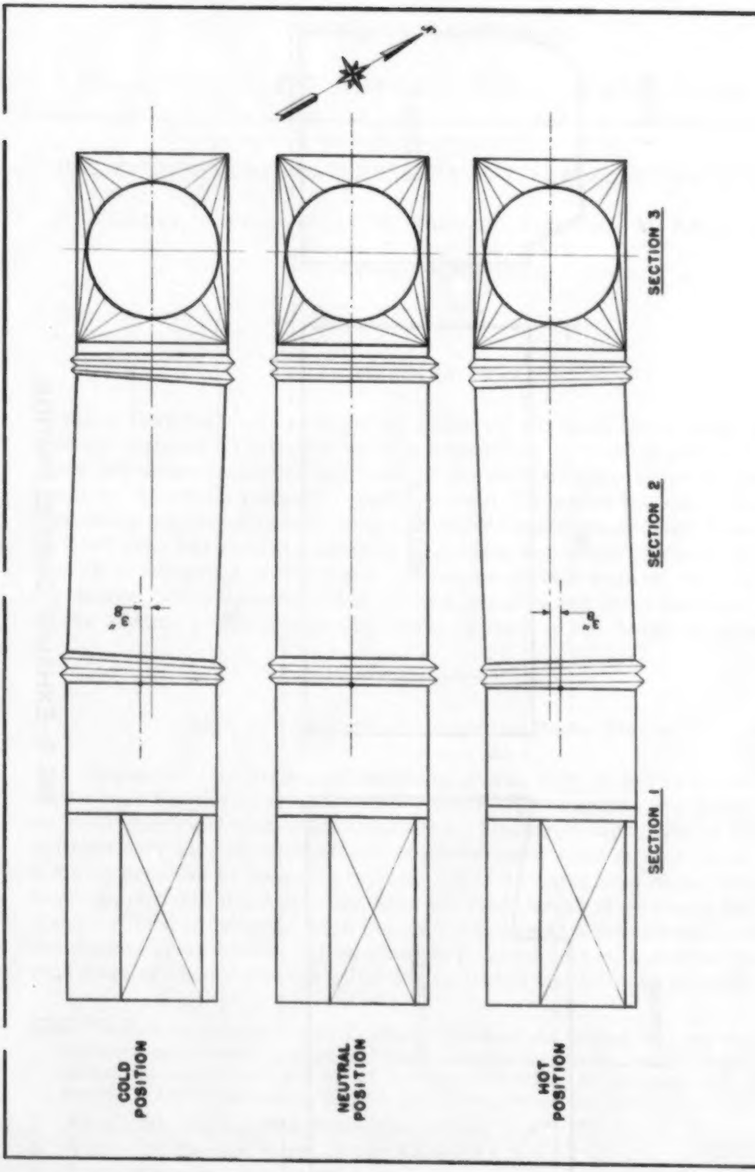


FIG.7.-EXHAUST DUCT PLAN

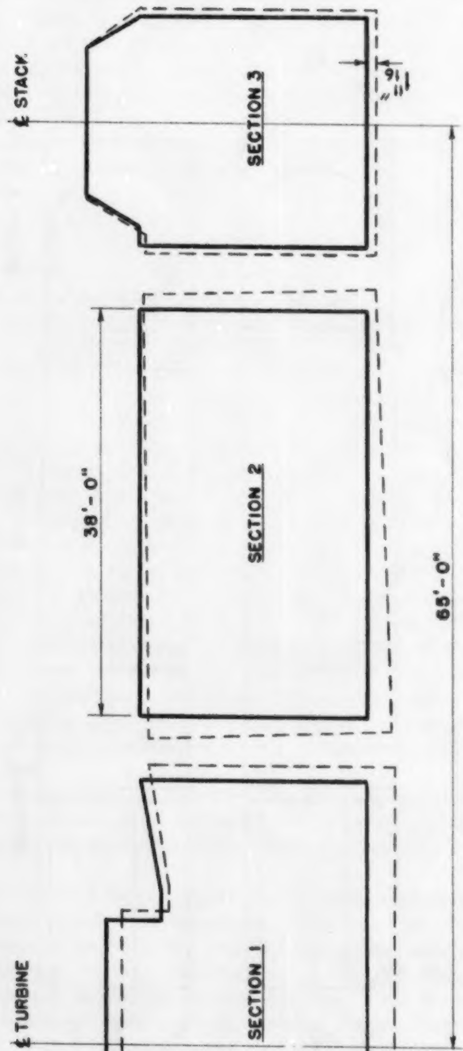


FIG. 8.-EXHAUST DUCT ELEVATION

Journal of the
POWER DIVISION
Proceedings of the American Society of Civil Engineers

CIVIL ENGINEERING FEATURES OF TVA STEAM ELECTRIC STATIONS

George P. Palo,[1] M. ASCE, Walter F. Emmons,[2] M. ASCE and Nathan E. Way,[3] M. ASCE
(Proc. Paper 1887)

INTRODUCTION

Since 1949 the Tennessee Valley Authority has built seven large steam electric stations. Forty-one units are operating in these plants and seven more are under construction. Most of the stations have space for further expansion. The units range in capability from 125 mw to 500 mw. The station capacities for the units operating and under construction range from 800 mw to 1,600 mw, and ultimate capacity in at least one of the plants is about 2,500 mw. It is the intent of this paper to discuss certain features of civil engineering design, some encountered at several stations and some peculiar to a single station, which may be of general interest in the design of steam plants.

Common Characteristics of the Steam Plants

Certain characteristics are basically common to all seven of the stations which have been constructed, and therefore the comments which will be made must be construed within this limitation. The large capacities of all of the stations have already been noted. All have rural sites so that space was not a major problem in the basic layout. All are located on a major river subject to an appreciable flood rise and have the plant areas at or above the respective flood of record. This places the plants at a considerable height above the normal river levels. All stations are fueled only with coal so their design requires large storage piles and facilities for delivery by barge, rail, and

Note: Discussion open until May 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1887 is part of the copyrighted Journal of the Power Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. PO 6, December, 1958.

1. Asst. Chf. Engr., TVA, Knoxville, Tenn.
2. Asst. Chf. Design Engr., TVA, Knoxville, Tenn.
3. Prin. Structural Engr., TVA, Knoxville, Tenn.

truck, or as many of these methods as feasible. At each project the main powerhouse is of the enclosed type with the turbogenerator room at grade. All powerhouses have the basement 40 to 50 feet below the generator room level, and the basement extends over the entire powerhouse.

Basic Items in Layout of Steam Plants

TVA's steam plants are designed by its Civil, Mechanical, Electrical, and Architectural Design Branches. Any part of a station reaches its final design by coordination of these four groups. In each case, however, one is designated the lead branch. For example, the layout of the main boiler and turbine building is led by the Mechanical Branch, while the layout for the office and service bay wings is the responsibility of the architects. General layout for the entire project is led by the civil engineers.

Five principal items control the general layout of a project.

1. Location of the main powerhouse on the best available foundation.
2. Location of the main powerhouse for service by railroad, highway, and river navigation.
3. Suitable layout for condenser cooling water facilities.
4. Layout for coal storage pile and coal-handling system.
5. Location of main powerhouse and switchyard suitable for outgoing transmission lines.

Each of the above items may be expanded upon briefly as follows, and some may be illustrated by reference to Fig. 1, which is a photograph of the Kingston Steam Plant—the largest of TVA's stations.

Fig. 1

Location of Main Powerhouse

With only the exception of the Shawnee station, the TVA steam plants have rock foundations. However, in many cases the rock is limestone with its usual cavities and fissures. In addition, the elevation of the rock surface often varies appreciably over the plant site. Accordingly, an early effort in the plant layout is to locate the main powerhouse on good rock at an elevation to minimize foundation excavation or substructure slab concrete. For the ultimate Gallatin station a difference in elevation of one foot in foundation rock represents a change in excavation of about 14,000 cubic yards. Avoiding cavities and fissures, if at all possible, not only reduces foundation costs but may avoid serious construction delay.

Service by Railroad and Highway

TVA provides railroad access to the end of the generator room and to the service bay area. This access has been developed by locating the service bay adjacent to the boiler room of the first unit with the structure often wrapping around the boiler bay wall as far as possible—for example, until blocked by stacks and fans. Such a layout permits rail and highway access to both service bay and turbine room from a single incoming highway or track. On several occasions when considering station layout an effort has been made to locate the service bay near the center of the ultimate station. For example, a station planned for an ultimate of eight units might have the first four units built to one side of the service bay and the remaining units on the other side. Such a layout would have the advantage of a service bay as close as possible to all of the operating equipment and the further advantage that a change in unit type or size after completion of the fourth unit could be accomplished more readily than when such a change is made simply by adding to an existing station cross section. However, the problems of access to such a layout have thus far always been so difficult that they have outweighed the possible advantages. For a powerhouse with over six units, a main door at both ends of the generator room has been found desirable even though only highway access can be provided to the door at the end farthest from the service bay.

Provision for Condenser Cooling Water

The layout of the cooling water system is, of course, peculiar to the project site. The early plants utilized reinforced concrete pipe as the water conduits. Later projects have generally been developed with tunnels for this service. In a number of cases an intake canal has been provided as a part of the general layout. With such canals the problem of floating trash and bedload of leaves may be serious, and the protection against these difficulties is discussed later in the paper.

Coal Storage Pile and Coal-Handling Facilities

Coal storage and the coal-handling system occupy a greater part of the project area than any other single item. The drainage water from the storage area is dirty and corrosive and therefore must be kept clear from the condenser cooling water system. An obvious way to accomplish this is to locate the coal storage downstream from the station with the cooling water intake upstream from it. This solution was used in the general arrangement of five of the seven stations, while special conditions at the other two made possible

layouts which could meet the requirement of keeping drainage water from other parts of the project.

It is desirable to arrange the coal storage pile and handling facilities so as to require a minimum length of conveyors. However, as successively larger stations were designed the importance of this criterion tended to diminish. If the coal storage pile and all unloading and crushing operations are at some distance from the main powerhouse, it is only necessary to increase the length of the connecting conveyors. This can be accomplished at reasonable cost. By the separation the coal-handling personnel became a completely separate unit in station operation with all necessary facilities such as locker rooms and shower rooms in the coal-handling area. Dust from coal operations around the main station is minimized and operating conditions improved. Architectural treatment for the main station can also be more satisfactory. The Gallatin station had a relatively rugged plant site which required coal storage at some distance from the station. This condition, first considered a difficulty, may now, after actual operation of the units, be considered an asset in the layout of the plant.

Outgoing Transmission Lines

A station with 2,000,000 kilowatts of capacity involves a large number of transmission lines and a layout to provide a suitable arrangement for their getting away from the station is essential. In all TVA projects the generators are in a long generator room with transformer yard and switchyard outside and parallel to the long wall of this room. The general orientation of the powerhouse and switchyard must be made suitable for the outgoing lines.

Site Development

Several of the basic items in the layout of steam plants discussed in the previous section may be considered to be "site development." However, in a broader discussion of this subject, other features should be mentioned.

Grading

For a large plant area of 500 to 800 acres located in the rolling country typical of most of the Tennessee Valley, large volumes of grading are involved in steam plant construction. Our plants have required movement of two to five million cubic yards of earth. With modern equipment the cost of this work is so low that it does not justify special layouts such as grading the main plant area in steps. Nevertheless, it is not essential that the entire graded plant site always be nearly level. An unusual example of this occurs at Gallatin, where the coal storage yard is more than 40 feet above the main floor of the generator room.

Powerhouse Location

Location of all TVA powerhouses is at a considerable distance from the water; thus, space is provided on all four sides for roads, parking area, and supplementary structures. This leads to greater flexibility in planning the plant layout.

Roads and Parking Areas

Because of the considerable distances involved on these large projects, roads and separate parking areas, with one car space allotted for each two employees, have been provided at all major features. This has helped reduce manpower requirements as there is a saving in manhours from the use of intraplant vehicles and from the employees' being able to drive directly to their place of work.

In order to match up with the ground floor of the main powerhouse, there is a tendency to use very flat grades on the paved and the unpaved areas around the buildings, and this was done on our early plants. Experience has shown, however, that in order to prevent rainwater from entering the structures and standing in pools on the roads minimum grades of two per cent for unpaved areas and one per cent for paved areas should be provided.

Space for Construction Plant

Large areas are required for construction plant both for initial construction and for the later addition of units to the station. This area should be located to provide smooth flow of construction materials during the initial construction and equally smooth flow and freedom from interference with operation of existing units when other units are added. An effective way to accomplish this is to provide construction plant area beyond the ultimate end of the powerhouse. A supplementary feature in this planning is to locate the coal yard in such a way that the conveyors to the powerhouse enter at the end occupied by unit No. 1. In TVA designs this has not always been followed. Two stations had the conveyors to the bunker room entering at the ultimate end of the powerhouse. However, this was done only because other major advantages warranted the acceptance of this disadvantage.

Unassigned Space Around Powerhouse and Other Major Facilities

As these plants are expected to be in active service from 25 to 40 years, space has been provided for additional structures and equipment which are sure to be desired to meet the continually growing technological and service developments. This policy has been amply justified, for example, at Johnsonville where in the past 10 years since its construction we have added hydrogen trailer ports for housing tank trailers which are connected directly to pipe lines servicing the hydrogen-cooled generating units, additional 20,000-square-foot floor area storage building, coal-sampling buildings for barge and rail coal, tugboat docking facilities, and facilities for collecting, storing, and loading onto trucks and railroad cars of salable fly ash. These features have been added without excessive cost and without setting up undesirable complications in the operation of the plant.

Main Powerhouse Concrete

On yielding foundations, a heavy structural concrete mat 6 to 8 feet thick has been provided to distribute the column loads; on unyielding foundations, a slab 2-1/2 feet thick has been used. It was assumed that hydrostatic uplift could act on the base slabs, which were from 40 to 50 feet below flood level. Various special provisions were used to permit the slab to resist flotation without having to provide additional deadweight of concrete for this purpose.

At Johnsonville 30-inch-diameter reinforced concrete anchors, varying from 15 to 17 feet on centers, project into the fractured chert foundation; at Shawnee a system of underdrains with sumps and pumps was placed in the sand-gravel foundation with floats which are set to prevent the ground water from rising above safe levels; and at Widows Creek, Gallatin, John Sevier, and portions of Colbert, where the foundations were solid rock, heavy steel rods were grouted into the rock foundation 5 to 10 feet on centers to anchor the thin concrete slab to the rock.

At Johnsonville and Widows Creek, where the outside columns of the building rest on top of the side walls of the substructure, counterforted walls were used to minimize the deflection at column bases, particularly at the base of the turbine room frames, when the backfill was placed against the wall. On the later plants the substructure extended beyond the outside column line; columns then continued down to rest on the base slab, and cantilever walls were used in the substructure. This simplified and reduced the cost of wall construction and backfill.

The possibility of hydrostatic pressure due to floods being added to the earth load on the cantilever walls was reduced considerably by the construction of a continuous french drain around the structure at a few feet above the normal level of the adjacent river or lake. These drains empty into an outside sump provided with float switch-controlled discharge pumps. The design of the cantilever walls assumed these drains to be fully effective in limiting the hydrostatic pressure on the walls.

As units are added to the plants, only temporary-type end walls 15 to 20 feet high are provided for the substructure until the ultimate number of units planned is installed. At a number of the plants construction-type steel bulkheads, which had been removed from the intake and draft tube passages as units were added to the TVA hydro projects, were utilized with only minor alterations to form the temporary end walls. Steel A-frames, bolted to the concrete base slab, supported the bulkheads which spanned horizontally. Outside the temporary end wall a sump with dual float switch-controlled discharge pumps is provided to prevent water from collecting and spilling over the temporary end wall into the powerhouse. This sump also receives the water from the french drain, previously mentioned, that controls the ground water outside the other substructure walls. When the plant is completed, a permanent end wall similar to the other basement walls is constructed and a sump or well with smaller capacity discharge pumps provided to care for the water from the french drain. A discharge pump capacity from 5,000 to 15,000 gallons per minute has been provided as dictated by the drainage area and permeability of the ground around the powerhouse.

The steam plant floors are all of concrete or grating, and the trend is definitely toward more concrete floors. This results from the increased use of heavy handling equipment, such as fork-lifts, and better housekeeping obtained by solid floors that will not let dirt and water drop through. A combined precast and poured concrete floor system was developed and used successfully at the John Sevier and Gallatin plants. This system consists of lightweight precast concrete slabs, serving first as the bottom floor form and then later with poured-in-place concrete on top as the lower portion of a combined slab. The precast slabs contain the main bottom reinforcement for the floor slab and are furnished with a rough surface to obtain good bond with the poured-in-place concrete. The precast slabs were purchased and erected by contract. The cost of these slabs in place, including the main reinforcement they

contain, is little, if any, more than that of the timber forms they eliminate. These heavily reinforced precast slabs have great construction advantage as they can be placed as the structural steel framing is erected and thus eliminate or greatly reduce the need for the usual temporary construction timber walkways and flooring. The net result is an appreciable reduction in final cost of floor construction.

Obtaining a satisfactory finish on the concrete floors is still a problem with the trend now being to require a monolithic finish wherever practical. Where a separate finish is required, the thickness for cement finish is limited to 1 inch maximum and for tile, 3 inches. Tile finish floors are used only in the main turbine room and public-use areas, such as lobbies, toilets, etc.

Settlement of Backfill Around Powerhouse

With the large powerhouses and rush construction schedules, it has not been feasible to restrict the backfilling operations to the summer and fall months, when moisture control of the fill can be closely maintained, and therefore at some plants considerable settlement in the transformer yard and the area around the stacks has occurred. To minimize the adverse effects of the settlement, the foundations of a main transformer, its takeoff towers, and its auxiliary equipment are built as a single concrete mat foundation. This type foundation has a more expensive first cost than individual footings for the separate features, but indications are that the saving in shimming and other adjustments required will more than compensate for the cost differential, and the danger of transmission line rupture due to differential settlement is practically eliminated. When the fill conditions around concrete stacks are questionable, steel pile supports are provided for the fan housing and gas ducts leading to the stacks.

It has been TVA's experience that where differential settlements could be expected of sufficient magnitude to interfere with the output of the plant it was more economical to reduce this differential by adding to the initial construction expense than to make compensations later by shimming or other measures.

Main Powerhouse—Steel

In general, the problems encountered in the design of the superstructure framing for the main powerhouses in TVA's system are not unusual in character. As might be expected, a boilerroom with its heavy beam and girder framing for the boiler suspension supports, main floors, and bunkers; its lighter framing for the boiler walkways, stairs, and miscellaneous platforms; and its bracing system presents more problems of coordination with equipment manufacturers and mechanical piping designers than problems of structural design. The same is true of certain areas in the turbine room except that here the architects and electrical engineers also become interested in what is provided in the way of structural framing.

Turbine Room Roof Framing

Except for unit 7 at Widows Creek, the main framing in the turbine rooms consists of welded steel rigid frames, which support the roof and crane runway. The spans of these frames vary from 86 feet at Gallatin to 122 feet at

Colbert. They are designed to take the lateral forces from the overhead cranes and wind loads in addition to the vertical, live, and dead loads. Lateral supports are assumed at selected boilerroom floor levels in the different plants, and horizontal reactions at these points are carried over and down the boilerroom bracing.

Close cooperation between the architects and engineers in the design of TVA's steam stations is demonstrated to its fullest extent in the turbine rooms. Careful attention was paid to the shape of the rigid frames, the detail of the crane brackets, the exposed bracing, and the wall and roof coverings in an effort to arrive at a treatment that would be simple, straightforward, pleasing to the eye, easy to maintain, and have the necessary lighting and acoustical properties, but still be as economical as possible. The turbine room at the Kingston Steam Plant, shown in Fig. 2, is an example. It is 895 feet long, 115 feet wide, and has a ceiling height of 55 feet above the operating room floor.

The maximum turbine room rigid frame span is 122 feet at the Colbert station. Investigations were made in designing it and the frames for the earlier plants to determine the economies, if any, that might result from using a conventional truss and crane column design in place of the rigid frames. Considering only the higher unit price of the steel and the heavier weight of the rigid frames compared with the truss scheme, there would be some economy in steel cost in the use of the truss scheme. However, some of this saving would be offset by the additional height of building required to accommodate a truss. The higher cost of maintenance of the truss throughout the life of the plant would further reduce this differential. The remaining additional cost chargeable to architectural treatment was considered justified.

In studying the framing requirements for the turbine room for unit 7 at the Widows Creek plant, another comparison was made of the two schemes of framing. In this case the span of the turbine room roof had increased to 126

Fig. 2

feet, which increased the weight differential somewhat in favor of the truss scheme. Also, over a period of years, from 1950 to 1957, the ratio of the unit bid prices for fabricated rolled steel sections compared with welded rigid frames in TVA stations had increased from 1 : 1.46 to 1 : 1.94.

These considerations led to a decision to use the truss scheme with conventional crane columns for this turbine room. Architectural, as well as housekeeping, requirements dictated the main trusses and the longitudinal stiffening trusses be of all-welded construction, using wide-flange sections for members.

Coal Bunkers

Coal bunkers vary in capacity from 2,200 tons per unit at the Johnsonville plant to 5,900 tons for the new 500,000-kw unit No. 7 at Widows Creek. The capacity at Johnsonville provides for approximately 40 hours supply, while that at Widows Creek No. 7 provides for 28 hours, indicating the trend to smaller bunkers when capacity is measured in hours of supply. All the bunkers are rectangular bin type with multiple hopper bottoms. They are supported at two levels by a system of beams and built-up girders designed to take both vertical and horizontal reactions resulting from the coal pressure. Wide-flange beams are utilized as horizontal ties between the side walls at the top of the bunker, at the intersection of the sloping bottom and side walls, and at intermediate points as required by the layout in the different plants. Vertical buckstays are used in the side and end walls of the bunkers. They are kept free from contact with the framing for the various floors in the boilerroom to allow deflection under full bunker loading conditions.

In the more recent plants the details of the vertical buckstays and bunker plates in the side walls were planned so that large sections of these walls could be preassembled on the ground and then erected as a unit. This resulted in a considerable saving in erection time and cost.

In the earlier plants the bunker plates were riveted to the buckstays and then seal welded for dusttightness. The individual hopper bottoms are of welded construction. Some difficulty was experienced in cleaning the bunkers as the coal would not flow out of the corners and the crickets in the hopper bottoms. This presented a very definite fire hazard. To remedy this situation, a 4-foot-wide, 16-gage stainless steel sheet was applied to each side of the crickets. The sheets were carried up in the corners to about 4 feet above the intersection of the sloping bottom and the side walls. A 10-gage stainless steel liner was also installed over the entire area of each individual hopper bottom. The stainless steel sheets were plug welded to the bunker plates and bent and crimped in the area of the rivets so as to rest on the rivet heads. In the more recently installed units, the bunker plates are welded to the buckstays. This facilitates the application of the stainless steel liners. In these units it was found to be more economical to continue with the use of the 16-gage liner plates than to use corrosion-resistant or stainless clad bunker plates. To provide further protection against hang-up of coal with attending fire hazard, corrosion-resistant plates were applied on either side of the tie beams through the bunker from toe to toe of the flanges to prevent the coal from packing on the bottom flanges. These remedial measures are now being applied to all of the bunkers in the TVA plants.

It has been TVA's experience that extreme care should be taken in the details of construction around the top of the bunkers and in the conveyor room

enclosure to prevent coal dust from seeping into the boilerroom. A dust-collection system designed to provide a negative pressure in the bunkers is installed in all the plants. However, under certain operating conditions in several of the plants, this design negative pressure has not been sufficient to retain the dust in the bunkers. From a standpoint of "plant housekeeping" there is no substitute for dusttight bunkers.

Boiler Suspension Framing

Because of the ever increasing size and capacity of the units installed in the TVA stations, the design of the boiler suspension framing has presented an interesting challenge to TVA's structural designers. It has not been as much a structural design challenge as it has been one of being able to read a crystal ball to determine just what the changing requirements of the boiler manufacturer would be as he developed the design of each new boiler.

Tight construction schedules made it imperative that the boiler suspension framing be delivered and erected as early as possible so that boiler erection could start as soon as the drum and other boiler components arrived on the site. Usually, the manufacturer in developing the design of a new boiler was not in a position to provide TVA with final boiler suspension loading information until quite late in his scheduled design period. In some instances this information was not forthcoming until after the shop drawings for the building steel were approved. However, in most cases they were able to provide enough preliminary information to allow TVA to establish the basic framing scheme and make a guess at the final size of most of the main members. This allowed the steel fabricator to prepare his advance bills for the material. As final information became available from the boiler manufacturer, the framing would be modified as required. This procedure is not desirable from a standpoint of keeping design costs down. However, it has been TVA's experience that, by not waiting to make a final design until final loading information is available, precious time has been saved in what is usually one of the critical periods in the construction of a station.

The main supporting members in the boiler suspension framing are built-up girders. In general, they range from 8 to 13 feet in depth. In one station it was necessary to use an 18-foot-deep girder in order to adapt the suspension framing for a new boiler to an existing cross section of boilerroom.

The boiler suspension framing for all of TVA's units except Widows Creek No. 7 has been designed using an allowable unit stress of 16,000 psi, compared with 18,000 psi for the remainder of the framing in the powerhouse. Some of this cushion in allowable working stress, while originally intended to provide a stiff supporting structure for the boiler, has also been used in a few instances when the boiler loadings have been revised after the steel had been received by the fabricator from the mills. These cases are few in number and, in general, did not affect the main members. For unit No. 7 at Widows Creek the allowable unit stresses have been increased to 18,000 psi and 20,000 psi.

Field Connections

In the earlier plants the field connections were riveted, with rivet bolts being used in inaccessible locations. The use of high-strength bolts appeared to present more advantages in helping to meet construction schedules. After having been given a trial on one of the smaller buildings at the Gallatin station,

their use has been specified in all of the recent powerhouse constructions. Cost reports show approximately equal costs for rivets or bolts but schedules can be speeded by the use of bolts.

Steel Stacks

Three of the steam stations built by TVA have steel stacks supported on the roof of the boilerrooms. At Watts Bar, built in 1940-44, each stack serves two units and is 16 feet in diameter and 50 feet high. The stacks for the first six units at Johnsonville and the first four units at Widows Creek were initially built to a height of 50 feet above the roofs with provision for extension to 150 feet. For units 5 and 6 at Widows Creek the stacks were built to a height of 150 feet above the roof and, subsequently, the stacks at Johnsonville were extended to the same height. These stacks are 14 feet in diameter, with the bottom 30 feet flared to 18 feet in diameter at the base. They were designed for a 25-pound-per-square-foot windload with single riveted lap joints and an allowable unit stress of 12,000 psi.

Before units 7 through 10 were added to the Johnsonville plant, a review was made of the distribution of stack gases from the first six units and studies were made to choose a maximum height of stack that could be constructed in the available space on the roof using the same cross section of the plant that was used for the first six units. It was determined that if one 20-foot diameter steel stack were used to serve two units, such a stack could be built on the roof of the boilerroom without structural difficulties to a height of approximately 279 feet above the roof, or 400 feet above the ground level. This height will provide satisfactory dispersion of stack gases for the 10-unit station. The bottom 96 feet of these stacks is a flared section 32 feet 8 inches in diameter at the base. Above the flared section the stack is cylindrical, having a 20-foot 8-inch diameter, for a height of approximately 136 feet. At the top of the 136-foot cylindrical section another flared section 30 feet 2-3/4 inches in height reduces the diameter to 14 feet. Topping this is a final cylindrical section 14 feet in diameter and 14 feet high. Fig. 3 shows the first of these two stacks just as steel erection was completed.

The stacks were designed to be self-supporting under the following considerations:

<u>Windload</u> of 25 psf on the projected area of the bottom 96 feet of stack.
<u>Windload</u> of 28 psf on the projected area of the remainder of the stack.
<u>Tension</u> on stack plates, net section—12,000 psi.
<u>Compression</u> in stack plates, gross section—10,000 psi.
<u>Lining</u>—3 inches of gunite.

The stack plates are butt-welded, with backup plates. The backup plates were bolted to the connecting plate at erection with high-strength bolts which were left in place after the joints were field-welded.

The stacks were investigated for cantilever vibrations. No resonance with eddy frequencies for all winds producing up to and including the design pressures were found.

Investigation of the stacks for ovaling indicated that the stack plates should be stiffened. In considering the ring stiffeners to be used, no allowance was made for the stiffening effect of the gunite lining and its reinforcing since the construction schedule required erection of the complete stack before placing any of the gunite lining. A circular ring consisting of a 1-inch-square bar

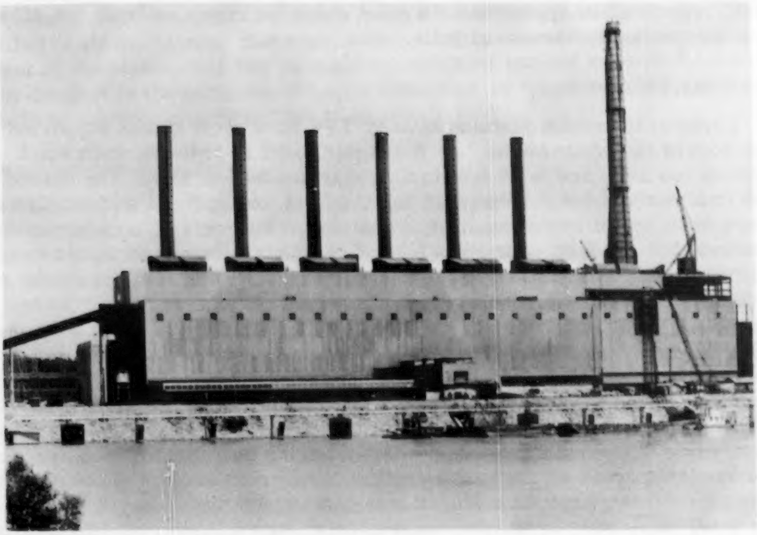


Fig. 3

with its centerline located 1-1/2 inches from the inside face of the stack plates was used as a stiffener. Beam action was developed by connecting this ring to stack plates by 3-inch-long web plates spaced on 12-inch centers. These assemblies were spaced vertically on 2-foot centers so they could serve the double purpose of stiffening the stack for ovaling and supporting the gunite reinforcing.

A 3-inch-thick continuous gunite lining is provided for the full height of the stacks. The reinforcing fabric is securely wired to the circular stiffening bars at 12-inch centers. "Atlas Lumnite" cement (or equal) was specified—the gunite to be mixed in the proportions of one part of cement to four parts of sand, and shot in one coat of 3-inch thickness.

The stacks are anchored by means of thirty-six 3-1/4-inch-diameter anchor bolts extending 6 feet 3 inches into a concrete stack mat which is supported in the plane of the boilerroom roof by plate girders. The depths of these girders were established so as to practically eliminate any possible vertical deflection under the design windloading conditions. Also, the building bracing was designed to hold to a negligible amount the lateral deflection of the stack mat under the same conditions.

A caged ladder is provided from the base to a circular platform near the top of the stacks. Two intermediate circular platforms are also provided. The platforms serve as supports for the navigation lights and for access to the painter's trolleys.

Since each stack serves two units, a vertical baffle wall is installed in the bottom of the stacks in front of the breeching opening. The wall is set at a 45-degree angle with the axis of the breeching.

Cooling Water—Structures

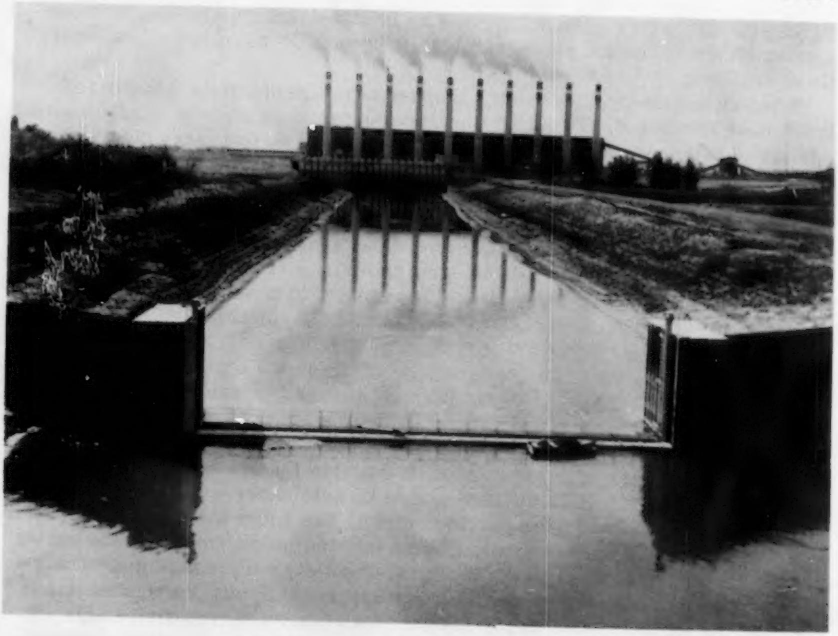
The cooling water system involves an intake structure and conduits consisting either of canals, pipes, tunnels, or combinations of two or more of these features.

When an intake canal is used, a number of problems in the handling of trash have developed. The traveling screens in the intake will handle a small amount of fine trash and larger pieces are stopped by the racks before the screens. However, as an extreme example of difficulty, at the Shawnee project, located on the Ohio River, tremendous quantities of waterlogged leaves were carried into the canal and settled to the bottom. Then under certain conditions of flow the leaves were agitated and carried along the canal in such quantities as to almost blank out the intake rack and screen and threaten the shutdown of the station. In addition, in times of flood, large floating trash occurred in such quantities as to make the problem of clearing intake racks a matter of major concern. For the decayed leaves the solution adopted is simply careful maintenance dredging with a small dredge purchased especially for this use. The dredge can be dismantled and carried overland by trucks so that it can be used at more than one station. For floating trash a trash boom has been used as shown in Fig. 4. This structure has considerable intricate details in order to make it suitable for the variable levels of the Ohio River and, in fact, to permit it to be held under water when the flood is so great as to spread over the flood plain. The boom has an effective depth of 4 feet and can be opened to allow boats into the intake canal. In the spring of 1958 the intake channel to the boom filled solidly with ice but essentially none passed it. The plant superintendent felt that that single experience had justified the entire cost of the structure. Two other less expensive trash booms have been constructed using surplus 39-inch-diameter steel tanks removed from the spillway of the Wilson Dam during a modification of the gate hoists at that project. These tanks could conveniently be modified to provide a depth of only 3 feet below water; however, actual experiences with moderate trash movement has indicated that this deflects the major portion of the floating trash into the main stream. An example of this type of boom is also shown in Fig. 4.

Provisions for Condenser Cooling Water

At the Kingston and Gallatin stations the condenser cooling water enters a canal from the reservoir of a hydroelectric project. These reservoirs are fed by streams of extremely low temperature discharge from high storage dams. During the warmer months of the year the water in these reservoirs attains a thermal stratification with the lowest temperature water flowing underneath along the riverbed. At these two projects skimmer walls which extended from above the water surface down to within about 15 feet of the reservoir bottom were constructed completely across the intake channel with the clear opening below the wall being sufficient to keep the velocity of flow under the wall less than about 0.7 feet per second at all times. During the seven months of warmer weather this low velocity under the skimmer wall does not break up the thermal stratification of the reservoir, and therefore only the colder water below flows into the intake channel. During the hottest periods these skimmer walls have resulted in condenser cooling water

FIG. 4



SHAWNEE TRASH BOOM

JOHN SEVIER TRASH BOOM

temperatures as much as 16 degrees below what would be available without the walls. For more complete information regarding these skimmer walls, see Proceedings Paper 1583.(1)

Coal Handling

A paper by one of the present authors(2) submitted to the Power Division at Atlanta convention in February 1954 discussed the coal-handling design for TVA steam plants with particular emphasis on the civil engineering features. Information in that paper will not be repeated, but experience in the last four years permits some additional comments.

Structures

The design of the coal-handling system must provide without compromise for the best possible mechanical and electrical arrangements for the handling of coal from the delivery points to the bunkers or to storage. TVA's civil engineers and architects have worked carefully to make the coal-handling system a series of sound, interesting structures. At all except the Gallatin station conveyors above ground are housed in enclosed truss structures. At successive stations the details of enclosure were modified to provide better air circulation to avoid unduly high temperatures within the enclosure in summer weather. At Gallatin the structural layout had a preponderance of short spans well adapted to beam or girder construction. This type construction was used for the entire system, and only a partial cover was provided over the conveyor belts. Fig. 5 shows a part of this system. The resulting structure is pleasing in appearance and for the particular requirements at Gallatin was an economical design. During the first few months of operation some belt slippage occurred during rains due to water on the back side of

Fig. 5

the belts. After study, the lagging on the head pulleys was grooved, and this effectively overcame the belt slippage to give satisfactory all-weather operation.

Docks

When possible, facilities were provided to receive coal by barge. Some plants receive practically all of their coal by barge, and extensive docks have been constructed at these projects. As the docks are for coal barges only and since these barges are being delivered repeatedly by a few contractors, it was thought that a lightweight type of construction could be made to serve satisfactorily. Therefore, at the Johnsonville Steam Plant clusters of 4 and 8 steel H-piles spaced at about 60 feet on centers were provided for guiding the barges to and away from the unloading crane and areas for storing loaded and empty barges. Barge operation, however, is subject to the whims of the weather and of river pilots; and as a result many of these pile clusters were knocked far out of line and maintenance was excessive. Therefore, on succeeding projects a conventional design of 16-, 20-, and 25-foot-diameter gravel-filled sheet pile cells spaced at about 80 feet on centers in the neighborhood of the coal unloaders and about 150 feet on centers in the barge storage areas was used. Fig. 6 shows this type of dock at Colbert. This type of construction has been satisfactory, and when a dock extension was required at Johnsonville to provide for four additional units, the entire dock was revamped by the addition of large-diameter gravel-filled sheet pile cells similar to the other installations.

Fig. 6

REFERENCES

1. "Thermal Density Underflow Diversion, Kingston Steam Plant" by Rex A. Elder and Gale B. Dougherty; presented at the June, 1956 ASCE Convention in Knoxville, Tennessee.
2. "Coal Handling Design for TVA Steam Plants" by George P. Palo; presented at the Atlantic Convention in February, 1954.

Paper 1888 December, 1958 PO 6

Journal of the
POWER DIVISION
Proceedings of the American Society of Civil Engineers

OCEAN COOLING WATER SYSTEM FOR 800 MW POWER STATION[a]

Robert H. Weight,[1] A. M. ASCE
(Proc. Paper 1888)

SYNOPSIS

The object of this paper is to set forth the problems which the civil engineer meets and is called upon to solve in making possible the construction of an ocean cooling water system for an 800 megawatt steam power station. The chief reason for locating a steam power station only a few hundred feet inland from the surf is the availability of unlimited quantities of cooling water. The cooling water system herein described is for Southern California Edison Company's Huntington Beach Steam Station located on the coastline 30 miles south of the city of Los Angeles. The initial capacity of the station is 400,000 KW. Each of two units has a turbine generator rated at 200,000 KW. The site provides for two future units of the same capacity or a total of 800 megawatts. The cooling water system is designed for both present and future requirements. The use of ocean water for cooling presents problems which are somewhat different from those where fresh water is used. The system provides for the effects of corrosion, control of fish, and control of marine growth. Model studies were conducted to assure economical control and handling of the tremendous quantities of water used and consideration was given to earthquake and subsidence in this location.

General Features

The Huntington Beach Steam Station is a part of Southern California Edison Company's rapidly expanding system. It is their fifth coastal steam station and they now have a sixth under construction. Rapid increases in power demands in the Southern California area due to accelerating industrial and

Note: Discussion open until May 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1888 is part of the copyrighted Journal of the Power Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. PO 6, December, 1958.

a. Presented at the October 1958 ASCE Convention, in New York, N.Y.

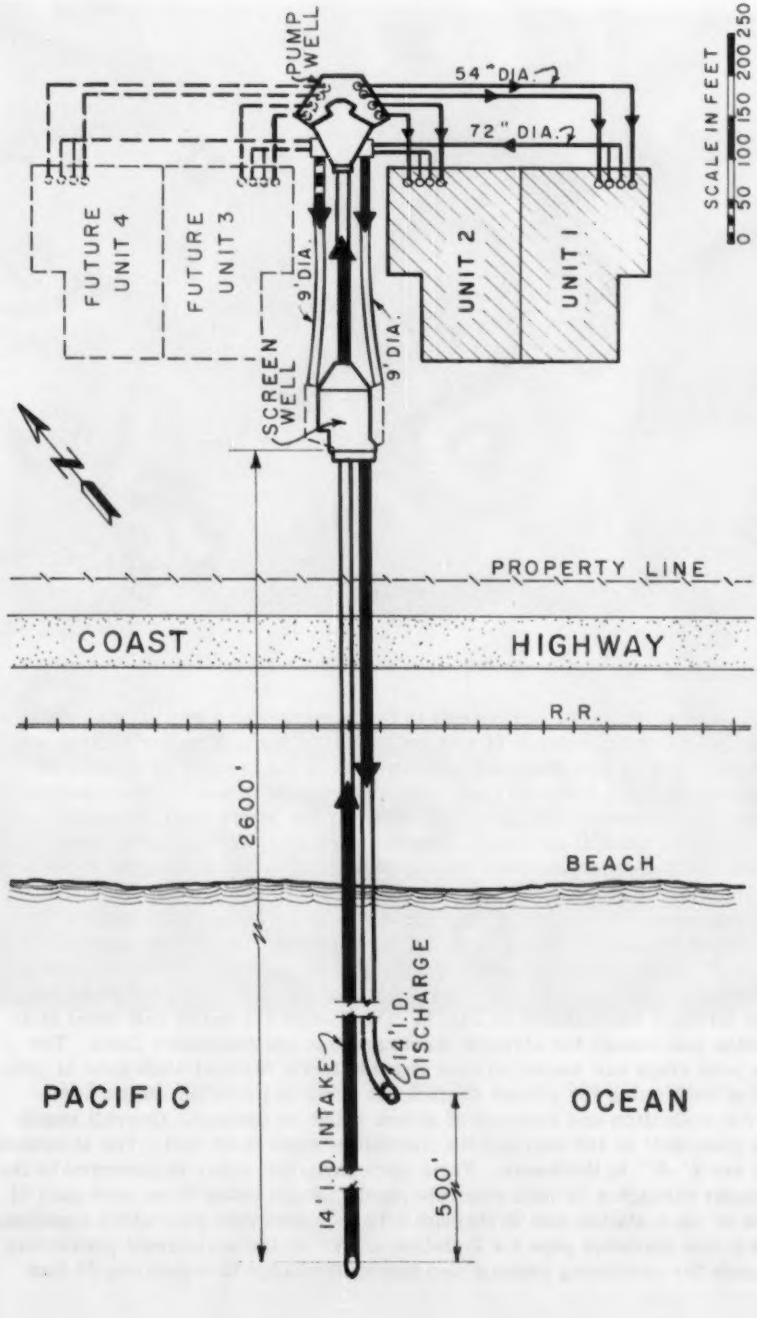
1. Superv. Civ. and Structural Engr., Bechtel Corp., Power & Industrial Div., Los Angeles, Calif.

population expansion has required an extremely active power development program. Speed in design and construction has been essential to meet the required schedules. Close engineering coordination and quick decisions have been a major factor.

The cooling water system for the Huntington Beach Steam Station is similar in many respects to the owner's El Segundo and Redondo stations. The experience gained in the design, construction, and operation of these two stations was incorporated in the design for Huntington Beach with as many improvements as possible. Fig. 1 is a plan view of the cooling water system showing the scope of work and general features. Maximum design water flow is 792 cfs. This tremendous quantity of water is sufficient if it were fresh water to supply the domestic and industrial needs for a city of more than 3,000,000 people.

The ocean intake and discharge conduits are located side by side 23'-0" center to center and extend approximately one half mile into the sea. The normal intake line extends seaward 500 feet farther than the normal discharge line and is on the up current side so there is little chance for recirculation of the water. The conduits extend shoreward under a public beach, a railroad, and Pacific Coast Highway to a screenwell approximately 150 feet inside the property line. Both pipes are 14 feet inside diameter made of reinforced concrete with walls 14 inches thick. Lightweight aggregates were used to reduce the weight and minimize handling problems. The units were precast in 16 foot lengths and installed with bell and spigot single rubber gasket joints. Fig. 2 shows workmen installing a rubber gasket on one of the units. Both lines are buried on the ocean bottom with a cover of approximately 5 feet of natural fill. The ocean end of these conduits upturns into an enlarged elliptical bowl rising about 10 feet above the bottom with its upper lip approximately 20 feet below low tide. The elliptical shape was used in order to clear the construction trestle. This position and shape insures an adequate water supply at all times and provides clearance for navigation. Fig. 3 shows workmen lowering a unit of the conduit into position through the trestle legs. A 60 ton gantry operating from rail tracks was used to handle the units and divers were used to assist in properly positioning them. A velocity cap was installed over the normal intake conduit to change entry flow characteristics for the control of fish. This feature came about as a result of conclusions reached in a study during development of final design.

At the screenwell the water flow is widened out to reduce velocity and provide for screening of fish, seaweed, or other debris that may be brought in. Fig. 4 is a plan view of the screenwell. It was considered an important design feature to position the centerline of the normal intake conduit on the centerline of the screens. Other important features shown are two nozzle turning vanes which are used to widen the water flow, two trash racks for rough screening, four screens for fine screening, four gates for periodic recirculation control, two stop gates to permit controlled dewatering if ever necessary, one closer gate to permit installation of future units without dewatering the screenwell, and two quiet areas in the forebay ahead of the trash racks for possible fish collection. Located on the screenwell deck are the motor operators for control of the gates, an "A" frame structure rigged with motor operated hoists for raising the screens, a screen wash system with splash housing and sluice trough for flushing, and provisions for a future traveling mechanical trash rake if ever required. Overall length of the screenwell structure is 112 feet and the maximum width, 86 feet. The structural walls are 3 feet in thickness.



PLAN OF COOLING WATER SYSTEM

FIG. 1

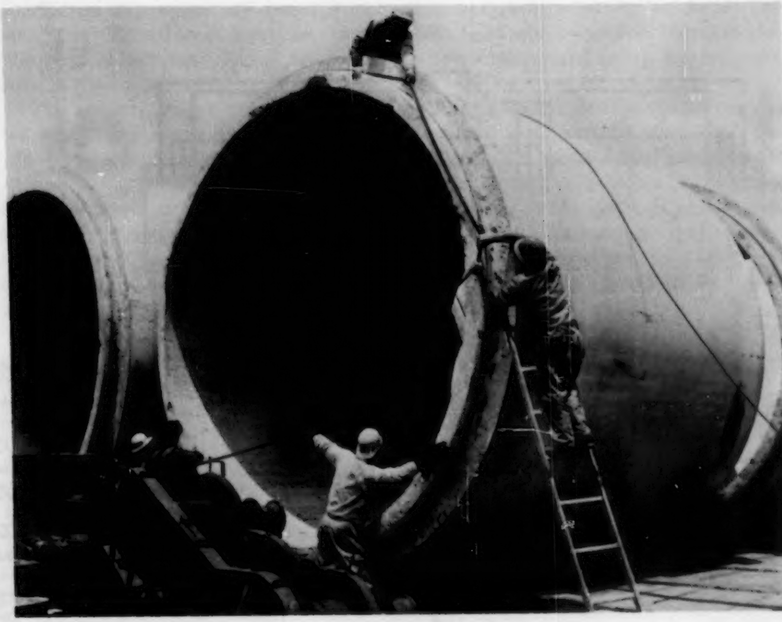


FIGURE 2 WORKMEN INSTALLING RUBBER GASKET ON UNIT OF 14'-0" OCEAN COOLING WATER CONDUIT

The conduit from the screenwell to the pumpwell is a rectangular reinforced concrete box culvert 11 feet by 14 feet in size. The box section was favored over a 14 foot diameter pipe as used in the ocean on the basis of schedule and cost. From a construction standpoint it was most advantageous to schedule the excavation and dewatering for the screenwell, pumpwell, and the connecting conduit as a unit. The box culvert could be constructed in the dry and could be accomplished without depending upon the availability of pipe. Final constructed costs proved to be favorable.

The pumpwell as shown in Fig. 5 is actually a widened extension of the box culvert which provides a compact arrangement for the installation of eight hugh pumps of 44,000 gpm capacity for operation at a head of 35 feet. This structure is below ground except for the upper walls of the pump bay shown strongly emphasized in Fig. 5. The pumps are below tide level at an elevation low enough for straight discharge into the condenser lines. The pump base rings are sealed against the tide and a vertical slide gate is provided at each pump for proper control. A sump is provided on the pump deck for collection and removal of storm water or leakage. Overall length of the pumpwell is 109 feet and the maximum width is 86 feet. The structural walls are 2'-6" in thickness. From each pump the water is conveyed to the condenser through a 54 inch concrete pipe. Return water from each pair of pumps or each station unit is through a 72 inch concrete pipe which combines into a 9 foot diameter pipe for 2 station units. At the screenwell provisions are made for combining present and future discharge flow into one 14 foot

FIGURE 3 WORKMEN IN PROCESS OF LOWERING 14'-0" CONDUIT INTO THE SEA

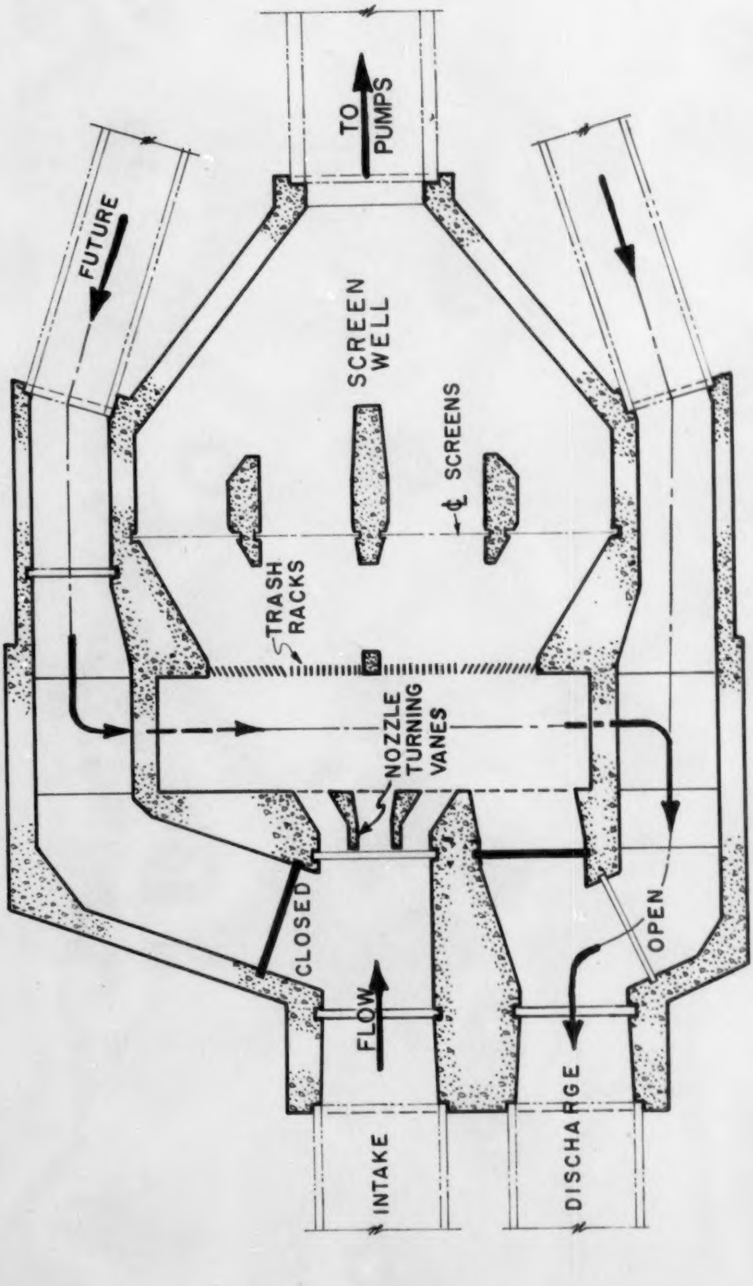


FIG. 4 PLAN VIEW OF SCREENWELL

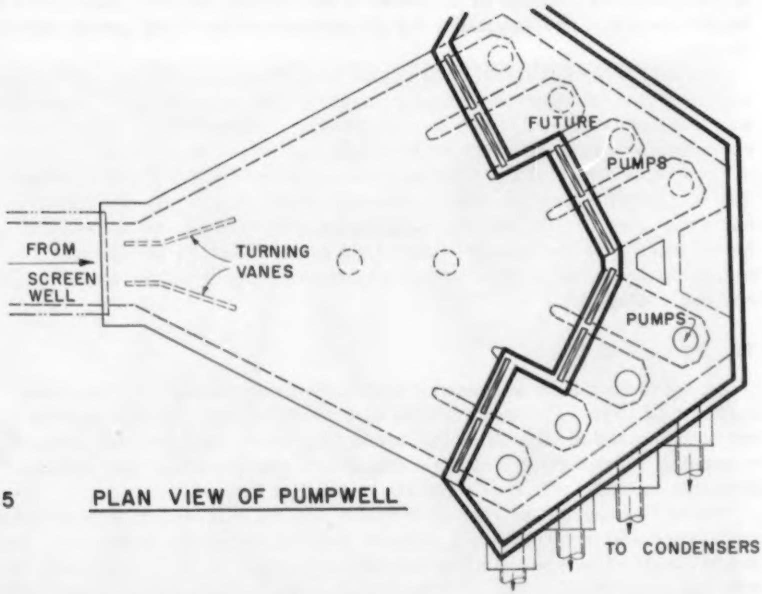


FIG. 5 PLAN VIEW OF PUMPWELL

diameter conduit. Dewatering of deep structures during construction was easily accomplished by the use of wellpoints.

Due to corrosion problems as much concrete and as little exposed metal as possible was used. Three inches of concrete cover on reinforcing steel was provided in all structures, type II cement was specified, and a design strength of 3000 psi minimum ultimate at 28 days was used. The entire system was designed to avoid excessive surge and water hammer and to minimize the effects of earthquake and subsidence.

Model Studies

Model testing of both the screenwell and the pumpwell was considered desirable to insure good hydraulic characteristics and best circulating water pump performance. The primary objective to be accomplished in both tests was that of attaining equal uniform flow to all unit components.

Probably a more economical design would be one where the screenwell and pumpwell combined into one structure, but decision to separate them was based upon two factors:

(1) To assure uniform water temperature to all pumping units during recirculation heat shock treatments by providing space and time to eliminate stratification and attain good mixing.
(2) To meet the required schedules for design and construction.

Knowing that the hydraulic characteristics of the pumpwell could exert considerable influence upon the circulating water pumps' performance, specifications for the pumps were prepared requiring the selected vendor to conduct a model test. This was to verify the configuration and characteristics

of the pumpwell concept or to assist in developing suitable improvements, and would place full responsibility for proper operation of the pumps upon the pump vendor.

Overall design of the station began in the summer of 1956. The schedule required that the station be in operation by the spring of 1958, therefore, it was absolutely necessary to accomplish the construction of the seaward conduits during the summer of 1957. Design requirements at the terminal of these conduits or the screenwell had to be determined by December 1956. The design and model testing of the screenwell was accomplished by the engineer-constructor and was programmed to meet the required schedules. Model testing of the pumpwell could not proceed until a pump vendor had been selected after preparing and processing specifications and obtaining and evaluating bids.

The Screenwell Model

Model tests on the screenwell structure were conducted in the late summer of 1956. Purposes of this test were twofold. One to be able to spread the conduit flow from the ocean to a width sufficient for proper screening without poor hydraulic conditions and resulting head losses. Secondly to make provisions for the control of fish.

Water flowing through the screenwell naturally takes the path of least resistance and would follow a straight line between inlet and outlet. This would cause excessive velocity through the center screens and make the outer screens ineffective. It would, therefore, be necessary to use the velocity energy at the entrance to spread the flow to the proper width. Computations indicated that four 11'-0" wide screens were sufficient to handle the maximum flow.

On previously designed coastal steam stations large numbers of fish have entered the screenwell causing maintenance and disposal problems. In conjunction with the need of obtaining a screenwell with proper hydraulic characteristics, it was desirable to make provisions for the solution of possible fish problems. Decision was made to provide quiet areas within the screenwell where fish could be collected and returned to the ocean alive.

The model was built to a scale of 0.10 full size. This scale would give good hydraulic similarity and was practical from a construction standpoint. The model consisted of three rectangular wooden tanks: a head tank, the model tank, and a discharge tank.

The head unit 5 feet wide, 7 feet long, and 3 feet deep represented the ocean. It had a side overflow weir which was used to simulate high and low tide. It was connected to the model tank by means of a rectangular wood pipe which represented the submarine intake conduit.

The model unit 6 feet wide, 11 feet long, and 3 feet deep allowed for flexibility in testing various internal arrangements and shapes. Fig. 6 shows a photo of the model and a portion of the discharge tank.

The discharge unit contained a slide gate and a V notch overflow weir. The slide gate controlled the amount of water flowing and the weir measured the quantity. With this setup engineers conducting the test could simulate high or low tide and one to four units operating.

Dye was injected into the system to observe the water flow. Darkened water area seen in Fig. 6 shows the flow spreading evenly from the entrance past the quiet areas provided for fish control to the screens in a final test.

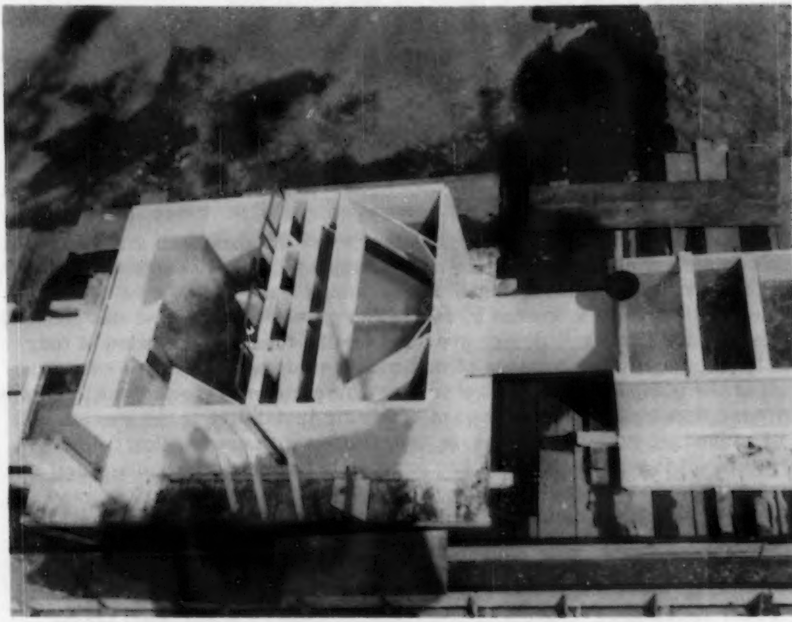


FIGURE 6 VIEW OF SCREENWELL MODEL

It was determined during the tests that the provision of nozzle turning vanes at the entrance making use of the velocity energy was the only way the flow could be successfully widened.

The entrance conduit is set at such an elevation that at low tide it is fully submerged. At high tide the tests showed a téndency for considerable slack water to remain stagnant on the surface. Modification of the model by flaring the top of the entrance conduit upward gave the water an upward velocity component which reduced the depth of slack water to a negligible amount and increased the effective depth of water flowing through the screens.

Some screenwell designs provide a dropped section or pit area immediately in front of the entrance conduit for collection of silt, sand, and shells. The theory being to reduce velocity here sufficiently to drop out and collect these solids for periodic removal by maintenance crews. Engineers in trying this in the model found that considerable turbulence and undesirable effects were caused. A dropped section was also tried at the screens which was intended to provide greater screening area. However, this too, proved ineffective since only slack water occupied the space. Corrosion effects are known to be considerably more severe in slack water. The structure was not

only simplified by providing a level bottom, but it gave better flow conditions. Silt or sand entering the structure was expected to be in small amounts uniformly dispersed and swept through the system without ill effects.

In making provisions for the control of fish, widened areas in front of the trash racks and each side of the flow path were installed. The theory was to provide quiet areas for possible congregation of fish that might enter. Using small live fish in the model these areas were found to be very effective in assembling them, however, a more complete discussion of the overall fish problem is presented under the heading, "Control of Fish".

The Pumpwell Model

By December of 1956, preliminary designs of the pumpwell structure had been completed, and the Ingersoll-Rand Company had been selected to furnish the circulating water pumps. These pumps were 44,000 gpm capacity each operating under a head of 35 feet. The present installation was for four pumps, but the pumpwell design provided for the future installation of four additional pumps. The purpose of this model study was to assure even flow to all of the pumps, and to assure proper flow pattern to the individual pumps. Improper flow conditions can lead to hydraulic instability at the suction bell of a pump causing varying pressure distribution with uneven flow to the impeller. These considerations are especially important in multi-pump installations. In a good design, vibration, cavitation, worn bearings, and other outward effects can be avoided.

The Ingersoll-Rand Company constructed a 1 in 20 scale model of the proposed pumpwell to be tested for design. The model consisted of an elevated tank with transparent top and bottom to permit observation of flow patterns. Circulating water pumps were simulated by stand pipes taking suction from each pump bay and discharging it to a common header leading to a test flow circulating pump. Each standpipe was equipped with a flow regulating valve and a flow indicating manometer which allowed control and measurement of individual pump bay flows. Recirculating water flow was measured on the circulating pump discharge by means of a venturi meter and a mercury filled manometer. This arrangement was also equipped with a flow regulating valve. Small brass flags were provided around the periphery of the suction of each simulated circulating water pump to give indication of suction flow pattern. Sawdust and colored dye were used to trace pumpwell and suction flow patterns.

Some pumpwell designs use low splitter walls on the centerline and below each pump bell. Preliminary tests using these demonstrated convincingly that they promoted extreme turbulence and unstable pump inlet conditions. For this reason the use of splitter walls was eliminated from the design.

It was also evident that turning vanes at the pumpwell entrance were necessary in order to achieve proper direction and equal distribution of the water to the pumps. Since it was desirable to use the turning vanes as structural supporting members, round column shapes were tried. These were found to be ineffective and the long vanes shown in Fig. 5 were used.

Tests were conducted using simulated flow conditions for two, four, six, and eight pumps in operation. An additional test with the four future pumps operating at 30% increased capacity was also conducted. These tests proved satisfactory in all cases. Operation using six pumps or less did not impose

flow problems for any sequence or arrangement. However, low flow and unbalanced flow tests were made to assure that no unusual operating condition would develop. It was found that the increased flow using 30% higher capacity in the four future pumps and the incidental unbalance did not create adverse hydraulic conditions under any predictable combination of circumstances.

It is believed that the final screenwell and pumpwell designs as developed by these model tests offer the most economical arrangement consistent with satisfactory hydraulic conditions. Moreover, it is believed these tests were instrumental in achieving appreciable savings in overall cost for both structures as well as minimizing pump power charges. It was thought by some that the irregular and unusual shape of these structures would cause increased construction costs due to forming difficulties. However, actually it was found these shapes offered a challenge to the carpenters and they put more interest into their work and enjoyed it, thus making the job efficient.

Control of Fish

During the operation of coastal steam stations, occasionally a large school of fish will enter the intake pipe, drift with the current to the screens, and completely clog the system when they reach that point causing possible expensive shut downs for fish removal. The Southern California Edison Company operators had experienced serious fish problems at their Redondo and El Segundo Steam Stations.

Aside from the nuisance factor and the expense of shut downs, it is desirable to avoid or prevent killing fish for both legal and moral reasons. Simultaneously with the development of the design for the Huntington Beach Steam Station screenwell, design engineers were authorized to perform a study leading to a solution of the fish problem at this and other stations. The ocean intake lines for both Redondo and the El Segundo Stations are very similar in design to the Huntington Beach Station. If a suitable solution for the fish problem could be resolved for any one of these stations, it would most likely be applicable at Huntington Beach.

Engineering studies of the fish problem were pioneered at El Segundo. A survey was conducted where observations were recorded and records compiled of the numbers of fish removed from the screenwell structure. It was in the fore chamber of the screenwell at El Segundo that large schools of fish could be observed. Being unable or unwilling to fight the water velocity at the entrance pipe for escape, they would swim endlessly in circles trying to avoid the bar racks or screens. These fish were periodically removed by maintenance crews after using a heat treating process and sold for fertilizer. Though a large variety and kinds of fish were found in the structure, about 90% of them were either sardines or anchovies from six to eight inches long. On July 22, 1956, over 12 tons of fish were taken from the structure, which emphasized the urgency of reaching a solution.

Two basic approaches to the problem were considered. One involved preventing the fish from entering the pipe line, and the other involved the use of fish pumps in the screenwell to recover the fish and return them to the ocean alive. The first method was recognized as the best solution, but the difficulties seemed insurmountable. The intake end of these conduits is one half mile out into the ocean and in 30 feet depth of water. Knowing that

electric barriers and sonic barriers had been used to scare fish, these devices were considered but rejected at this location because necessary experimentation would be difficult and expensive. Pulsed energy to frighten fish by use of electric or sonic devices would require an electrode system and power source on shore connected by wiring. At this depth and distance to sea when subjected to wave action and corrosion, such mechanisms were considered impractical.

The second approach had been tried successfully by design engineers at the River intake of the Contra Costa[2] Steam Plant of the Pacific Gas and Electric Company. In experiments there it was found that for fish pumps and collecting devices to be successful the fish must be concentrated in small areas. In these and other tests it had been discovered that fish do not like areas of high velocity. It frightens them. It is also known that fish swim upstream into the current, even though they are being carried by the current. As a result, obstructions like trash bars or screens are approached tail first. Since the fish cannot see the obstruction they struggle from being carried into it and move laterally to the side.

Making use of this theory the Huntington Beach screenwell model was enlarged in front of and at each side of the trash bars to provide two still water areas out of the flow path for the fish to congregate. Making use of tiny model size fish one inch long which were furnished by the Health Department of the City of Los Angeles, the model was tested and observations recorded. Hundreds of these small fish were turned loose in the system and better than 80% accepted the theory by congregating in these quiet areas. At this point, since time was of essence, engineers conducting the model test decided to provide quiet areas in the prototype of the screenwell at Huntington Beach and proceed with final design. If other means failed, here was one possible solution to the fish problem.

The Velocity Cap

After realizing how much fish avoid areas of high velocity there was a feeling the velocity principle could be utilized for the better solution of keeping fish from entering the pipe at the source. Attention was again directed to the pipe in the ocean. Flow patterns were sketched and velocities calculated at various points. The flow was vertically downward with the entrance velocity less than one foot per second. For such a low entrance velocity, why couldn't the fish escape? It appears that fish in a large volume of water above the entrance were slowly drawn downward as if on a descending elevator and were unaware of peril. Once into the conduit deep enough to feel the velocity pull they were confused and could not escape. Earlier observations had shown fish to be familiar with horizontal velocities which they can resist, but vertical velocity flow is confusing and they cannot cope with it. It was decided to try changing the flow pattern from vertical to horizontal by means of a lid over the conduit intake which was called a velocity cap. This proved to be the answer to the problem. Fig. 7 shows schematically how the velocity cap was applied to the conduit intake.

2. See State of California Department of Fish & Game Fish Bulletin No. 92, Studies of Fish Preservation at the Contra Costa Steam Plant of the Pacific Gas and Electric Company, by J. E. Kerr.

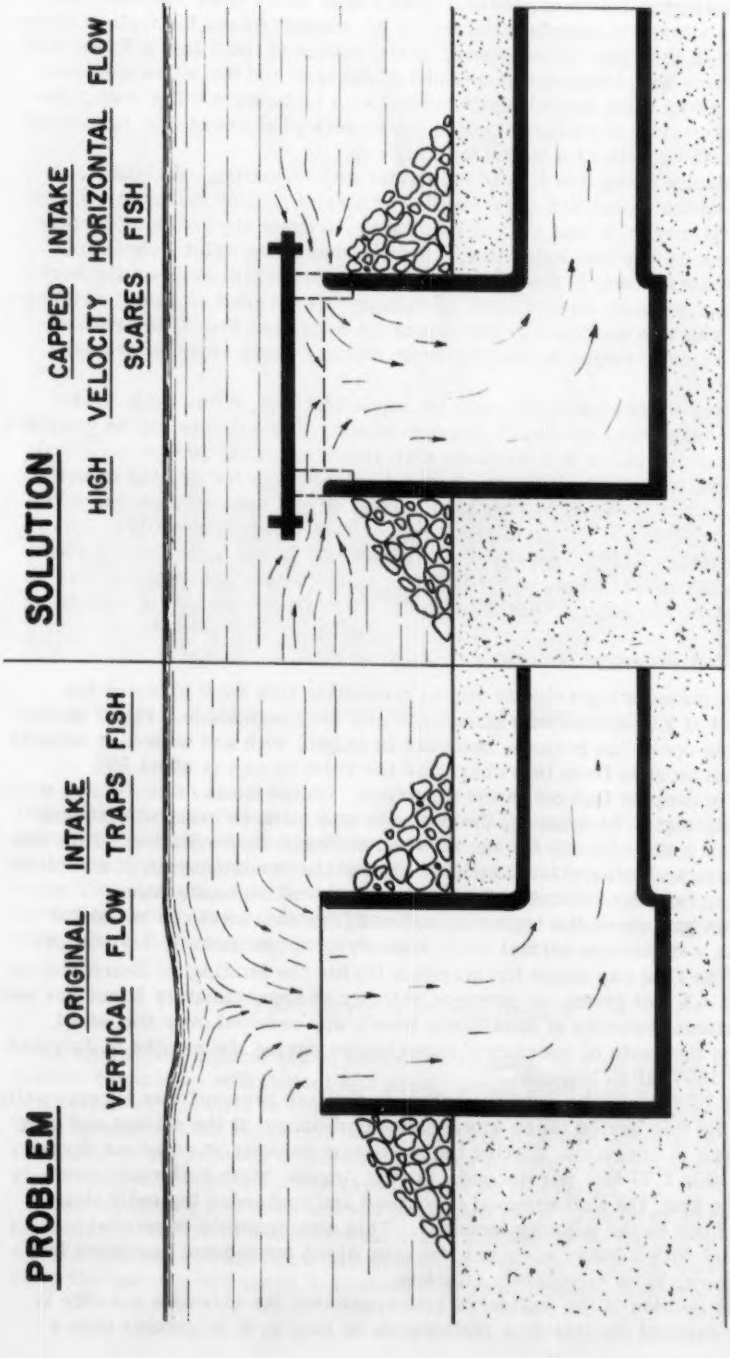


FIG. 7 SOLUTION TO FISH CONTROL PROBLEM

The Huntington Beach screenwell model upon which tests had been completed was altered to simulate the end of the conduit intake for further tests. A vertical 16 inch pipe was installed in the bottom of the 5 feet x 7 feet tank. A supply hose was connected at one end of the tank and the water duffused through a 2 foot thick gravel layer to eliminate turbulence. The water discharged by gravity downward through the 16 inch pipe where test runs could be made with or without a model velocity cap.

Test results using live fish in the model were startling. Without a velocity cap the small fish were swallowed up and rapidly disappeared into the pipe. However, it was almost impossible to draw any fish into the pipe when a velocity cap was being used. It was amazing to watch schools of small fish swim towards the pipe and then turn and swim away as the horizontal tug of velocity warned them of danger. As a result of model observations, the cap was modified by thickening its edge (see Fig. 7) to prevent too close velocity sweep around the brim giving a more truly horizontal entrance.

Following successes of the velocity cap model test, a full scale prototype was constructed for the El Segundo intake. The velocity cap as provided at El Segundo consists of a concrete slab 12 inches thick, 29 feet long, and 23 feet wide, and weighs 43 tons. It has 4 hairpin legs for seating upon the lip of the intake tower and is anchored by its weight only. There was some difficulty in setting it due to heavy seas, but this was successfully accomplished in June of 1957. A manhole was provided in the center of the slab which would provide possible access into the opening of the conduit. Fig. 8 shows a photo of the prototype about to be lifted from a barge for setting.

Velocity Cap Prototype Success

Effectiveness of the velocity cap in preventing fish from entering the screenwell at El Segundo was immediate and very noticeable. Fig. 9 shows comparable operation periods, one year in length, with and without a velocity cap. It can be seen from this chart that the velocity cap is about 95% effective in keeping fish out of the structure. On the basis of successes with the velocity cap at El Segundo, the decision was made to proceed with construction of a velocity cap for the Huntington Beach Steam Station. This was quickly designed and installed with the rest of the conduit terminal structure. It proved to be quite economical and is virtually maintenance free.

The flow gap above the intake lip at the El Segundo intake is set at 2.0 feet giving a maximum normal entry velocity of approximately 3.5 feet per second. The flow cap above the entrance lip for the Huntington Beach Station was set at 4.5 feet giving an entrance velocity of approximately 2 feet per second. Maximum velocity at Huntington Beach was reduced over that at El Segundo on the basis of operators' experiences during the months of July and August of 1957, at El Segundo.

During July as can be seen from Fig. 9, the fish removal was exceptionally low. During this period there was a scheduled outage at the station and only one unit was in operation, making the maximum velocity at entrance during this time only 1.75 feet per second. During August, when both units went back on the line, the fish removal increased and engineers logically thought that it was due to the velocity increase. This was probably somewhat coincidental with a heavy seasonal fish run, since subsequent operation has proven the cap to be completely effective.

It is the opinion of the engineers concerned that the entrance velocity is not highly critical for this type installation as long as it is greater than a

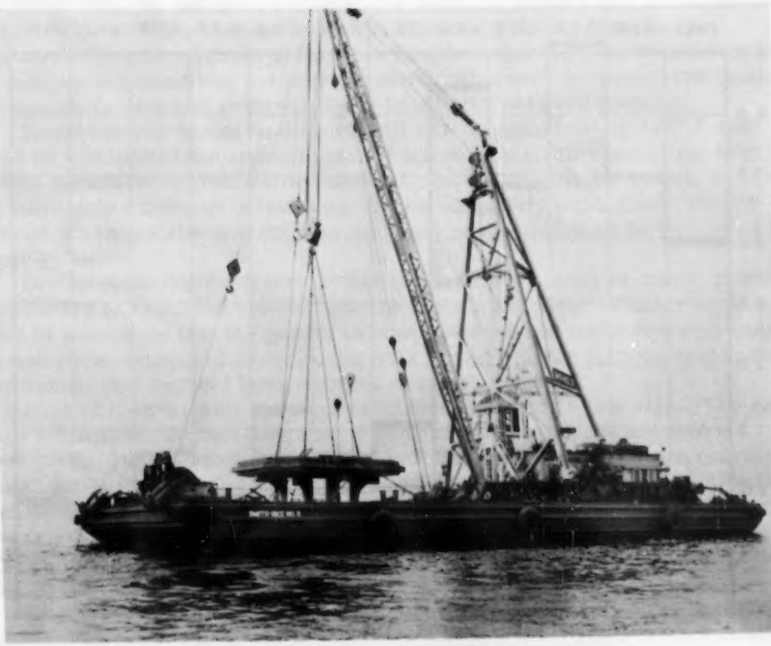


FIGURE 8 VELOCITY CAP ON BARGE READY FOR INSTALLATION

fish normally experiences. A range of 1 to 3 feet per second at the lip is recommended as acceptable for design. Since the flow is radial, the velocity pull is variable and different fish will be frightened at different distances from the entrance. The first unit at Huntington Beach is presently in operation, which gives a flow of one fourth design maximum, and there are virtually no fish entering the structure.

The Control of Marine Growth

In almost any natural ocean water environment marine growth or tiny marine organisms will collect and grow. Small shell fish such as mussels will be among the first to begin this. If not controled, these organisms will build up and become incrusted on the inside of pipe and structures to a thickness of the order of 6 inches. In order to have a satisfactorily operating circulating water system, this growth must be controlled.

Marine growth can be killed and prevented from building up in these conduits by the use of chemicals such as chlorine, or by the use of heated water. The most economical and preferable method of killing marine growth is by the use of a hot water heat shock. Normal temperature rise as the

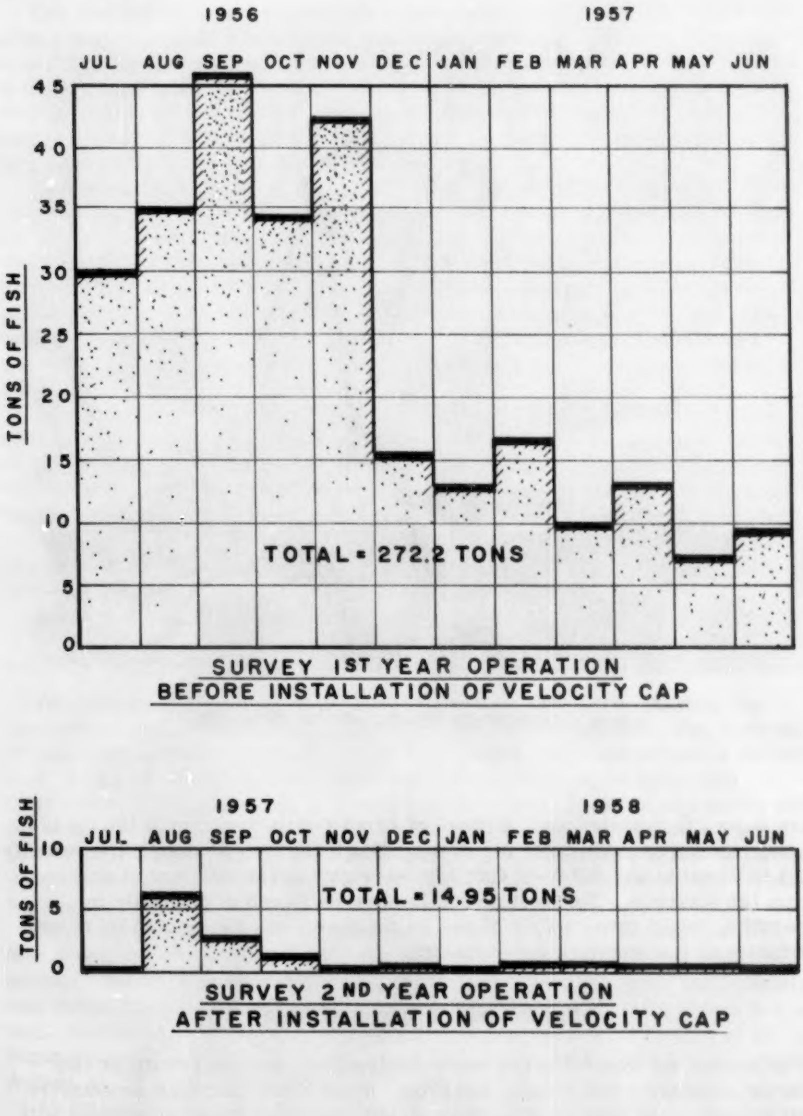


FIG. 9

EL SEGUNDO STEAM STATION, UNITS 1&2
CHARTS SHOWING TONNAGE OF FISH
REMOVED FROM INTAKE STRUCTURE

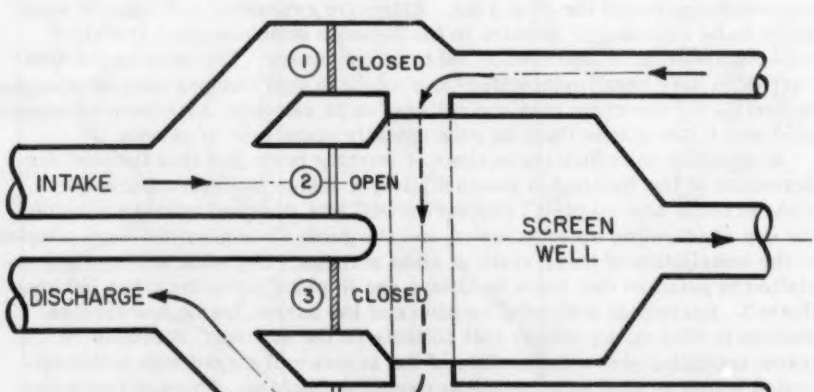
water passes through the condensers is about 20° F from approximately 62° to 82° F. This is not quite sufficient for adequate control and of course the intake lines do not normally have heated water in them. Four motor operated vertical concrete slide gates have been provided in the screenwell to accomplish throttling for partial recirculation with resulting additional temperature rise and reversal of the flow in the seaward conduits.

Temperatures during heat shock will reach approximately 105° F and will be maintained for approximately 4 hours. By making use of the heat shock treatment approximately once each month, the marine growth which is of negligible thickness in this time can be adequately controlled. Fig. 10 shows schematically how the flow reversal is accomplished by the use of the four gates.

During reversal of the flow of this tremendous quantity of water, it was necessary to check the effects upon the system for possible water hammer and to make sure that the pumps were not starved nor the screenwell caused to overflow because of surge during this period. It was also necessary to determine that critical temperatures were not exceeded.

Each of the four gate openings is 13 feet wide and 15 feet high. The gates are vertical slide concrete gates, 8 inches in thickness and are motor operated. The speed of the gate leaf is 1 foot per minute. Station operators can initiate the flow reversal cycle by pushing a button making possible the accomplishment of the full cycle in 15 minutes. The cycle can be stopped at an intermediate position to hold heat shock temperatures for the four hour period, but controls are interlocked so that gates 1 and 4 or 2 and 3 cannot be closed simultaneously. (See Fig. 10).

Engineers calculated water levels and resulting temperatures in the screenwell for the shortest permissible and possible cycle. This was accomplished by solving ten simultaneous equations for progressive increments



NOTE: TO REVERSE FLOW
OPEN 1 & 3
CLOSE 2 & 4

FIG. 10 DIAGRAM SHOWING OPERATION OF RECIRCULATION GATES

of time. This solution could have been obtained rapidly by the use of an electronic computer, but at the time it would have cost more to properly program the work than to complete the solution longhand. Fig. 11 shows graphically the results for the full cycle which proves the water level remains within permissible bounds and the temperature does not exceed 106 degrees F. There was no water hammer problem in the system.

Screening and Trash Racks

Screening of cooling water for the removal of debris and fish is almost always essential in order to prevent fouling of the condensers. When ocean water is used for cooling a materials problem is created in preventing corrosion to the trash racks and screens. Wherever possible, concrete was used in the entire cooling water system, but when we come to screens, some form of metal is nearly always used. In most installations traveling water screens are used which are fabricated primarily of steel, with some minor critical working parts such as chain rollers, and the screen wire made of either bronze or stainless steel. To reduce corrosive attack on these screens, coatings are applied which are sometimes augmented by cathodic protection.

Traveling water screens can either be operated continuously or intermittently depending upon the debris load. They are flushed by high pressure water jets into a disposal trough. In order to maintain steel traveling water screens in a reliable condition in ocean water, experience has shown annual haulout is required, coupled with extensive repair. On the basis of an economic evaluation, traveling water screens fabricated entirely of stainless steel were installed at the Southern California Edison Company Redondo Steam Station. After five years of trouble free service with negligible maintenance the same type of screens were specified for the El Segundo Steam Station. However, at El Segundo extensive corrosion damage to the screens occurred in the first year. Extensive reworking and repairs were found to be necessary. Repairs to the Redondo stainless steel traveling water screens have also been found to be necessary. The reasons for this corrosion have been investigated[3] and minor design changes such as changing materials for the chain pins and rollers, as an example, have been incorporated which now makes them an economically sound type of screen.

In an effort to reduce the number of working parts and thus the cost for screening at the Huntington Beach Station, a design incorporating vertical slide screens was adopted. The screenwell was designed to make possible the use of traveling water screens, and the guide slots provided were adapted to the installation of these vertical slide screens. The slide screens are installed in pairs so that there is always one in place while the other is being flushed. Horizontal stiffening members of the screen frame are used as shelves to haul up any debris that collects on the screens. A simple "A" frame extending above the surface of the screenwell rigged with motor operated hoists is used to raise the screens for flushing. These screens can be flushed automatically or manually by the operator pushing a button.

Fig. 12 shows a diagram of the screens. The screens are designed to resist

3. See <u>Corrosion Experiences with all Stainless Steel Traveling Water Screens</u> by William M. Jakway. Presented at 14th Annual Conference National Association of Corrosion Engineers, San Francisco, California, March 1958.

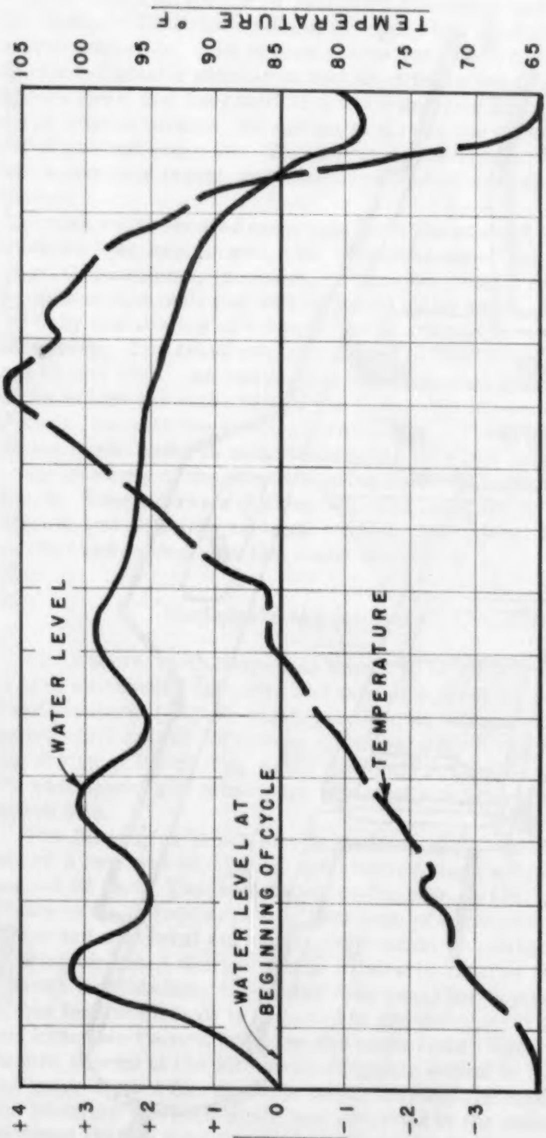


FIG. 11 HUNTINGTON BEACH STEAM STATION SCREEN WELL WATER LEVEL AND TEMPERATURE DURING REVERSAL OF COOLING WATER FLOW

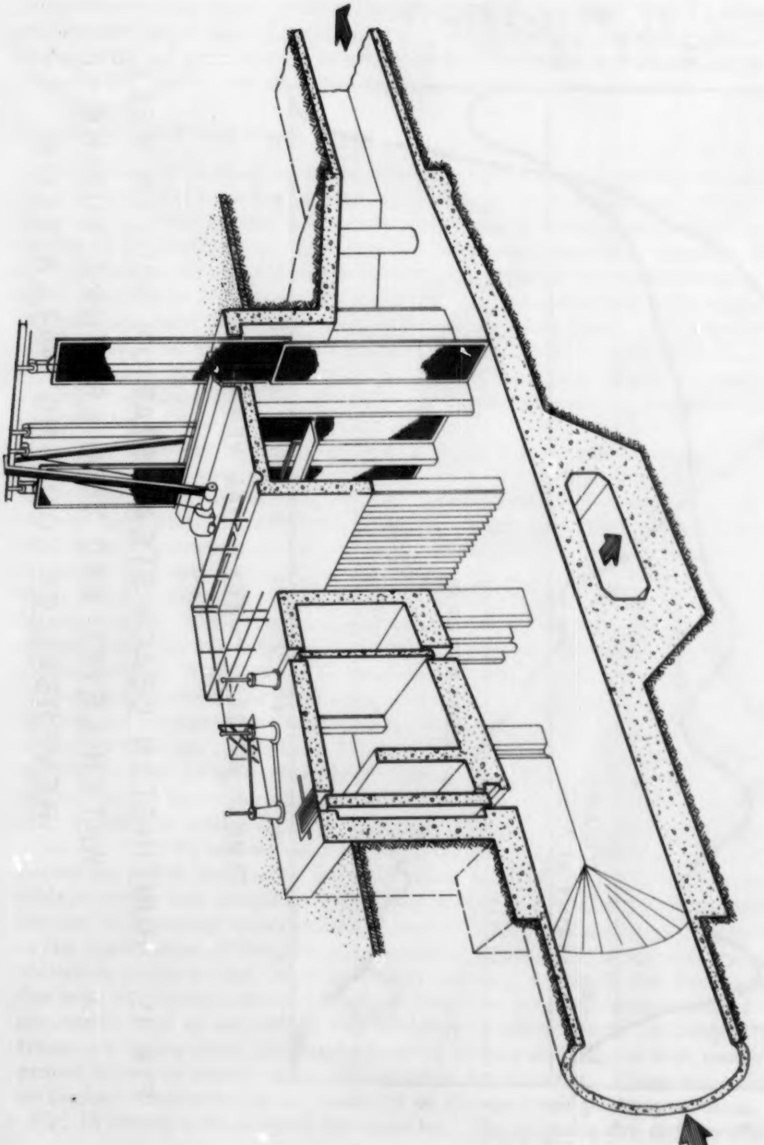


FIGURE 12 SECTION THROUGH SCREENWELL SHOWING VERTICAL SLIDE SCREENS

a pressure resulting from a head differential of three feet, however, they are set to flush automatically if the head differential becomes 8 inches.

In an effort to reduce or minimize corrosion and maintenance problems, the Southern California Edison Company has been willing to pioneer the use of new materials. The screen guides have been fabricated out of a fiberglas reinforced plastic similar to that used in the manufacture of boats. The screen itself and the connecting bolts and clip angles have been fabricated out of silicon bronze. Splash housing over the screen wash jets is fabricated out of precast concrete. The debris flushed from the screens is collected into a concrete trough and discharged out to sea with the main seawater discharge.

Trash racks located upstream from the screens are used to remove large trash such as logs, sticks, etc. Previous experience has shown this trash to be small in volume, therefore, to save the cost of expensive mechanical equipment this material will be raked up by hand. Provisions were made for easy installation of a future motor operated traveling mechanical rake if necessary. Two trash racks are used in this structure, each 19 feet wide, and 19 feet high. An interesting and important feature about these trash racks is that the outer half of the vertical trash bars have been set slanted to be in line with the nozzled stream flow. This was found to be desirable during model tests to avoid turning the flow and rendering useless the accomplishments of the nozzle turning vanes. This feature can be seen in Fig. 4. Trash racks are constructed of standard A7 structural steel, all welded, and all joints are seal welded. After fabrication they were blast cleaned and coated with two coats of tar-set.

Earthquake and Subsidence Considerations

Since Southern California is known to be located in a zone of relatively severe earthquake intensity and is also a great oil producing area, design considerations for both earthquake and subsidence had to be given to the entire station site. Of course these considerations were incorporated into the design of the cooling water system. Preliminary to design, a report on the earthquake and subsidence potential was prepared for the Huntington Beach site.

The Huntington Beach site is located only 15 miles south of Long Beach where a removal of oil from the underground pool has caused subsidence to exceed 22 feet. The devastating earthquake of 1933 in the Long Beach and Southern California area was the cause of extensive revisions to building codes and a general serious consideration to earthquake design. The Huntington Beach Station site is located in an area in which earthquake activity and intensity is greater than usual for Southern California. The active Inglewood fault is believed to dip underneath the site at some depth and branches thereof traverse the immediate vicinity at shallower depths. Severe shocks at the site could originate either in the Inglewood fault zone or the more distant San Andreas fault. Earthquake intensity of 8 as measured on the Modified Mercalli scale has occurred in the general locality and it is believed that an intensity of 9 could easily develop. For these reasons an acceleration factor of 0.2G and consideration for the resulting ground movements was used for the design.

It was found that subsidence at the Huntington Beach Steam Station could

result from two unrelated causes: (1) Tectonic adjustments and general geologic consolidation of recent sediments, (2) Oil production in the vicinity. The present rate of tectonic adjustments was found to be about 0.03 feet per year and accelerating about 0.001 feet per year. Subsidence from this source was estimated to be a total of from 1.5 to 3 feet during the next 50 years.

Subsidence caused by possible oil production was found to be influenced by several facts. No oil producing sands immediately underlie the station site. Oil producing pools in the area surrounding the site are small and will not cause subsidence of the site itself. Potentialities for subsidence of the yet unexplored offshore leased areas are unknown. Under varying assumptions considering all of these factors, subsidence caused by oil production was estimated to range from 0 to 5 feet maximum. While the sum of both tectonic and oil production subsidence was indicated to range between 1.5 feet and 8 feet, design considerations using a total from 3 to 5 feet was considered prudent and safe.

Specific items incorporated into the design of the cooling water system for earthquake and subsidence were as follows: (1) All structures are analyzed for lateral forces due to an earthquake acceleration of 0.2G, (2) All pipe and structures were joined together using flexible connections to take into account possible earth movements, (3) The screenwell and pumpwell structures walls were extended 3 feet higher than they would have been normally to prevent tide overflow in case of subsidence.

CONCLUSIONS

A large variety of interesting problems for the civil engineer are encountered in the design of a cooling water system for a large coastal steam power station. It is the civil engineer's never ending duty to find improvements in his design for better economy, efficiency, and reliability of these systems. Consideration of the experiences of others is highly important in the field.

Journal of the
POWER DIVISION
Proceedings of the American Society of Civil Engineers

WATER SUPPLY TO THERMAL POWER PLANTS[a]

E. J. Stankiewicz[1]
(Proc. Paper 1889)

ABSTRACT

Water supply to thermal power plants is the chief factor in locating plant sites, because of cooling water requirements, and accounts for the largest single nationwide water use. This paper discusses quantities required, sources, circulating water systems and uses, and also reviews the water supply systems for several power stations.

INTRODUCTION

Water—the world's most valuable resource—is the vital circulating liquid which is as indispensable to thermal power plants as blood is to the human body. An adequate supply of water is one of the most important factors governing selection of plant sites, and converting this supply to plant use is a problem which always requires painstaking analysis to solve—and often requires considerable ingenuity as well.

The great bulk of the water supply is required for condensing purposes since practically all generating stations—other than those which must provide heat and process steam—operate condensing. Delivery of this water to the condenser and discharge back to source constitute the circulating water system.

A small percentage of the total water demand is required for station service water supply. This includes low-pressure and high-pressure service water, ash sluicing and fire protection systems which take suction from the circulating water system, and filtered water and treated water systems which are usually supplied from deep wells or city water mains, although they may

Note: Discussion open until May 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1889 is part of the copyrighted Journal of the Power Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. PO 6, December, 1958.

a. Presented at the October, 1958 ASCE Convention in New York City.

1. Chf. Structural Engr., Sargent & Lundy, Chicago, Ill.

be supplied from the circulating water source. The problems involved in furnishing station service water are fairly routine, so this side of the water supply picture will not be further discussed; rather, the entire emphasis will be on the circulating water supply. However, it should be noted that while furnishing station service water is routine, treating it is not, and is a subject all by itself.

Circulating Water Demand is Large

Large quantities of water are used for circulating water systems. The classic remark is that "In some power plant installations the amount of water necessary for cooling is so great that the entire river flow is diverted through the plant".

A direct appreciation of these large quantities may be gained from a study of Fig. 1, which gives a comparison of daily circulating water requirements for various size stations, based on 100% load factor, as contrasted with total water demand of several U. S. cities.(1) As may be seen, a station of 100,000 kw capacity requires 115 million gallons of water a day for condensing purposes—or more than the entire daily water consumption for the 629,000 population of New Orleans, Louisiana. Extended, this adds up to 42 billion gallons a year.

For a large station, such as the 1,075,000 kw Kyger Creek Plant of The Ohio Valley Electric Corporation, more than 1.1 billion gallons of water per day circulate through the condensers. By comparison, the largest city in the world—New York—with a population of 7,891,957 averages 1.14 billion gallons daily for all purposes except power plant use. On a yearly basis the 1.1 billion gallons amounts to 400 billion gallons.

Relation to National Water Supply

The saving grace of this large water demand of thermal power plants is that it is, in the main, a nondestructive and nonconsumptive use of our water resources. The water is diverted, yes—but it is not polluted and it returns to its source in essentially undiminished volume. Actually, it is somewhat the better for its thermal detour, because it has been thoroughly screened of debris and in almost all cases has been chlorinated.

Nor is the natural water cycle seriously disturbed, for the complete, and continuous, diversion is a matter of only minutes and except in unusual cases is not even apparent. Compare this with irrigation, for example, where much of the water used evaporates to the atmosphere and may or may not return as rainfall to its original source, thus altering the natural water cycle by reducing the water resources of the area. Or consider various municipal or industrial systems which draw water from streams and discharge polluted water back into them, thereby seriously diminishing the usefulness of the downstream flows and thus effectively reducing the regional supply of water.

In view of the increasing seriousness of the total water supply problem of our country, and the continual expansion of electric power production, this nondestructive, nonconsumptive water demand of thermal power plants is indeed a happy marriage of good use with good return. For example, total thermoelectric capacity of the country for 1957 was 102 million kw, with a 0.59 capacity use factor.(2) In terms of condenser cooling water this amounted to 70 billion gallons per day, equivalent to 27% of our total national use of 261 billion gallons of water daily(3) for all purposes including electrical

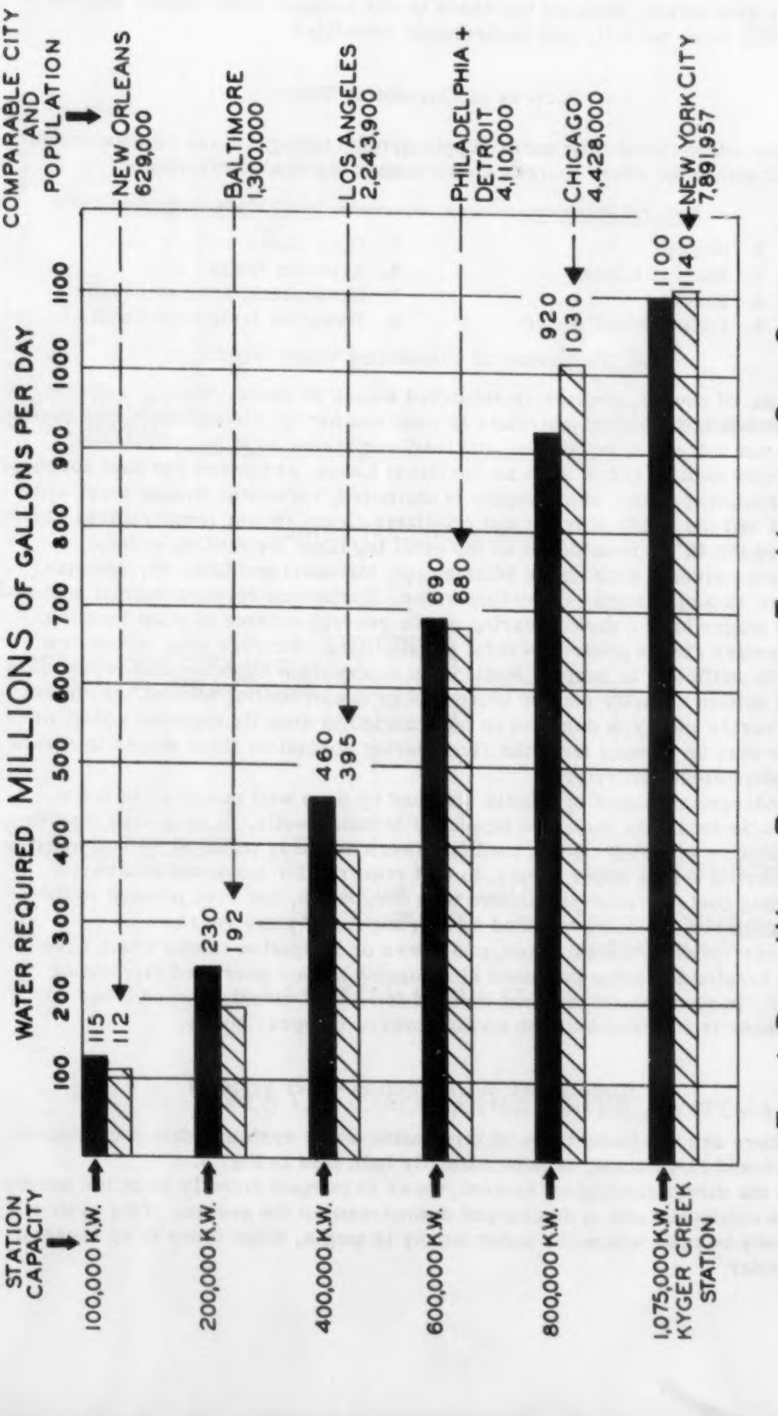


Fig. 1 Daily Water Requirements For Various Size Stations Compared With Daily Water Consumption Of Typical U.S. Cities

power generation. Imagine the chaos in our national water supply picture if this 27% were not fully and immediately reusable!

Sources of Circulating Water

Sources of circulating water supply may be either natural or man-made. Fig. 2 shows the usual sources under each of these classifications:

Natural Sources	Man-Made Sources
1. Oceans	1. Deep Wells
2. Natural Lakes	2. Artesian Wells
3. Rivers	3. Reservoirs, artificial lakes
4. Underground Water	4. Power or Irrigation Canals

Fig. 2—Sources of Circulating Water Supply

Oceans, of course, provide an unlimited supply of water. Special selection of equipment and building materials is required for the circulating water system to resist salt water corrosion, and tidal variations must be considered.

Major natural lakes, such as the Great Lakes, are one of the best sources of circulating water, since supply is unlimited, variations in lake level are small and the water is fresh and relatively clear. Water temperatures rarely exceed the 80° F. considered as the ideal top limit for cooling water.

Large rivers, such as the Mississippi, Missouri and Ohio, for example, assure an ample supply of cooling water. Variations between normal pool and flood stages have a direct bearing on the general scheme of plant location.

Smaller rivers present several possibilities. Average year round flow may be sufficient to support stations up to a certain capacity, and beyond this limit station capacity may be increased by use of cooling towers. If stream flow varies widely, a dam can be constructed to directly impound water, or water may be pumped from the river during normal or floor stages to create an independent reservoir.

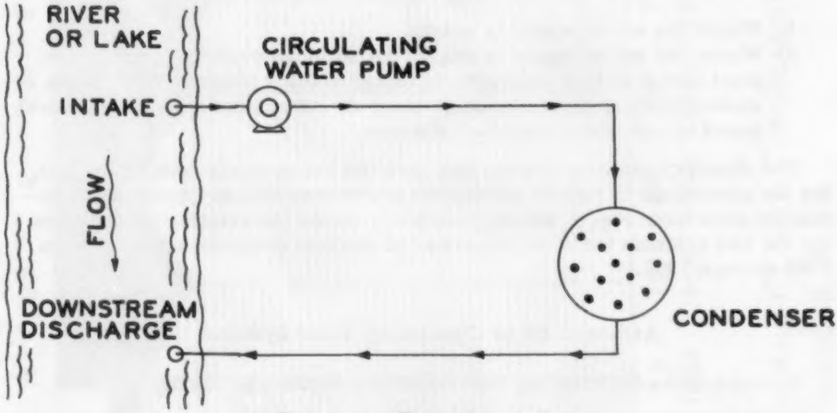
Underground water is usually obtained by deep well pumping; in some favorable locations it may be tapped by artesian wells. It is always used in conjunction with reservoirs, cooling towers or spray ponds to reduce pumping, beyond initial water supply, to that required for make-up; otherwise pumping costs become prohibitive with deep wells, and ever present is the possibility of seriously reduced flow in abnormally dry years.

Reservoirs, artificial lakes, and power or irrigation canals which have been created for other purposes also furnish a good source of circulating water. In some cases they can be used for direct circulation—in other instances in combination with cooling towers or spray ponds.

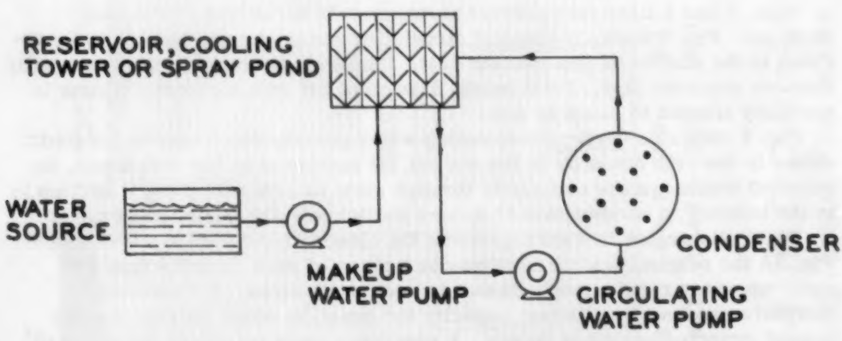
Basic Types of Circulating Water Systems

There are two basic types of circulating water systems, direct circulation and closed circulation, as schematically indicated in Fig. 3.

In the direct circulation system, water is pumped directly from the source to the condenser and is discharged downstream of the source. This system can only be used where the water supply is ample, since there is no reuse of the water.



DIRECT CIRCULATION



CLOSED CIRCULATION

FIG. 3 TYPES OF CIRCULATING WATER SYSTEMS

In the closed circulation system, the cooling water is in a closed cycle between condenser and a cooling tower, spray pond or reservoir. The water source need furnish only the original water plus, relatively speaking, a small amount of make-up. This system is used for two general conditions:

1. Where the water supply is scarce.
2. Where the water supply is ample, but so located with respect to the plant that it is less expensive to install cooling towers, spray ponds or reservoirs than to continuously pump direct against a large head imposed by excessive height or distance.

The direct circulation system has been the more widely used of the two, but the percentage of closed circulation systems is steadily increasing, as may be seen from Fig. 4, which graphically shows the relative percentages for the two systems for a large number of stations designed and built from 1945 through 1957.(4)

Arrangement of Circulating Water Systems

Arrangement of circulating water systems depends primarily on:

1. The basic type of system, whether direct circulation or closed circulation.
2. The total height through which the water must be lifted.
3. Whether the plant is a grade level station or a basement type station.

Figs. 5 and 6 illustrate several arrangements for direct circulation systems. Fig. 5 shows horizontal circulating water pumps, which may be located in the station or just outside of it. Intake or discharge lines are usually steel or concrete pipe. Total height of suction lift with horizontal pumps is normally limited to about 15 feet.

Fig. 6 indicates vertical circulating water pumps, which may be located either in the crib house or in the station. If suction is at the crib house, intake and discharge are ordinarily through steel or concrete pipe; if suction is in the building, a combination of flumes and tunnels are customarily used.

Fig. 7 illustrates two arrangements for closed circulation systems. In Fig. 7A the original source of supply is a river of such variable flow that make-up water requirements cannot be met at all times. A reservoir is therefore used, with sufficient capacity for make-up water storage for the longest expected period of drouth. A reservoir pump transfers the water to the cooling tower basin, from which the circulating water pump then circulates the water to the condenser and back to the top of the cooling tower. Thereafter only make-up water goes from reservoir to cooling tower. If the river source provides sufficient water at all times for make-up requirements, then the reservoir is of course not required.

The arrangement of Fig. 7A is very widely used where closed circulation is necessary, and an interesting example of it is Vermilion Power Station which will be reviewed in some detail later in this paper.

In Fig. 7B the original source of water is from deep wells. A reservoir may or may not be required, depending on year-round adequacy of the wells.

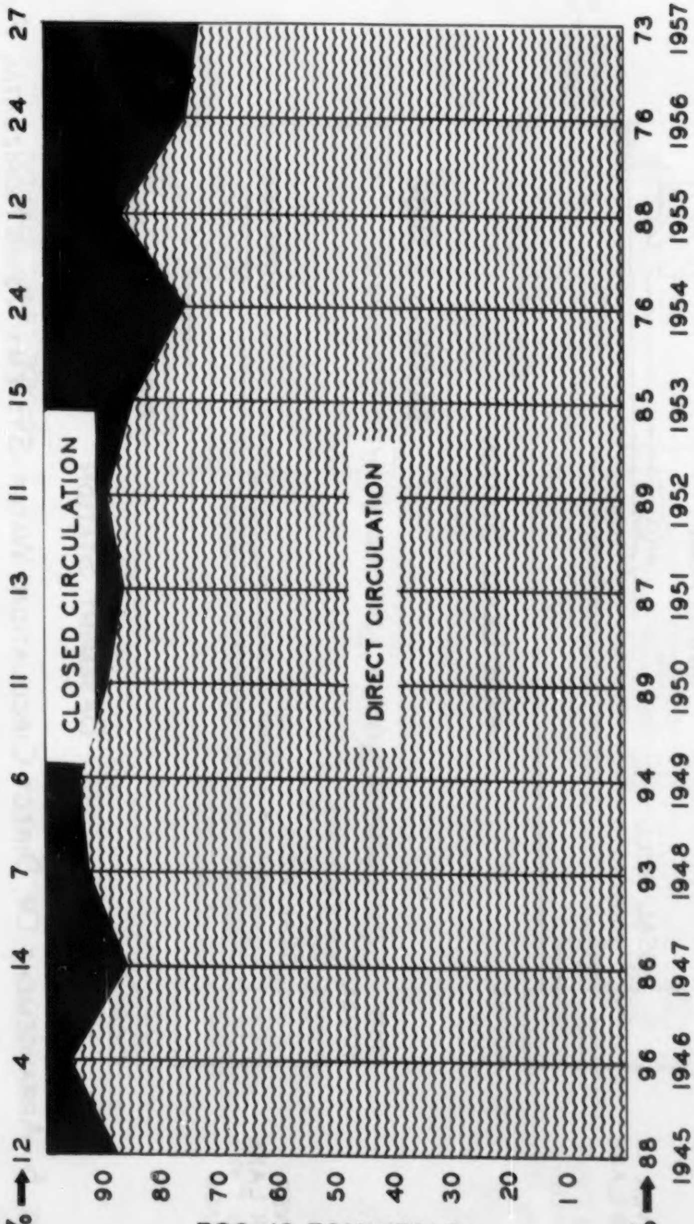


FIG. 4 COMPARATIVE USE OF DIRECT CIRCULATION AND CLOSED CIRCULATION WATER SYSTEMS FOR YEARS 1945 THROUGH 1957

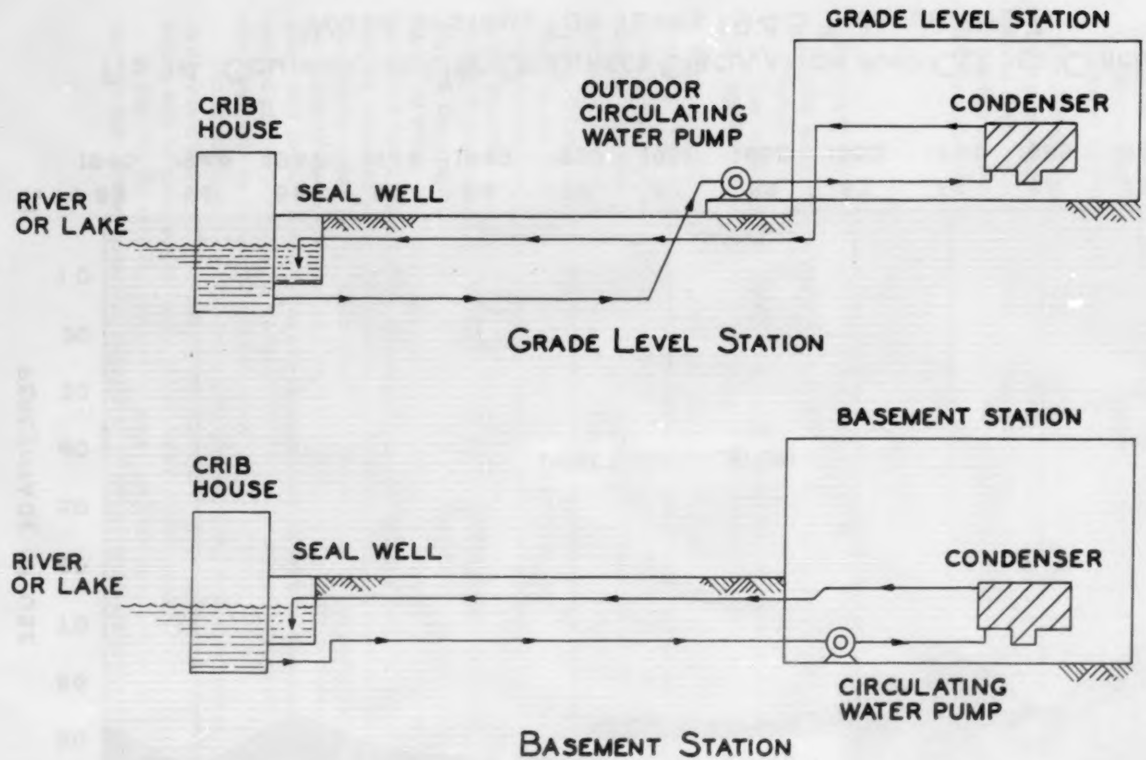


FIG. 5 ARRANGEMENT OF DIRECT CIRCULATION WATER SYSTEMS USING HORIZONTAL PUMPS

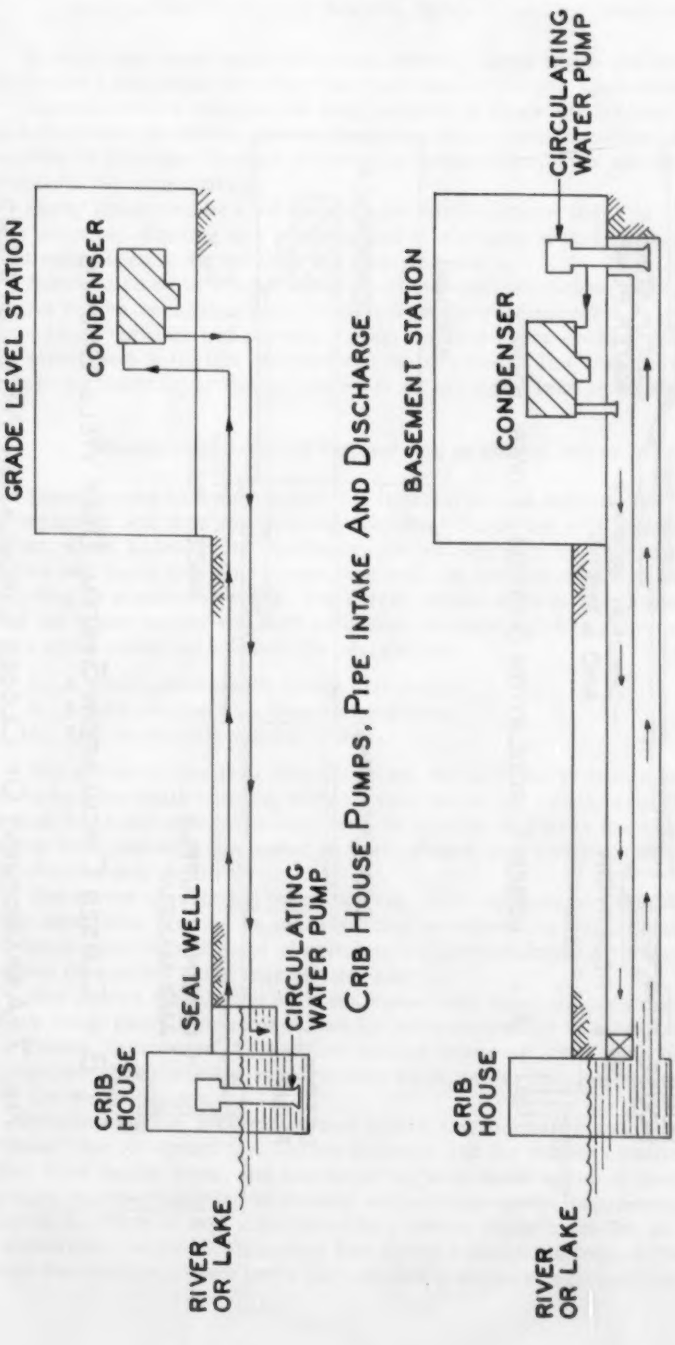


FIG. 6 ARRANGEMENT OF DIRECT CIRCULATION WATER SYSTEMS USING VERTICAL PUMPS

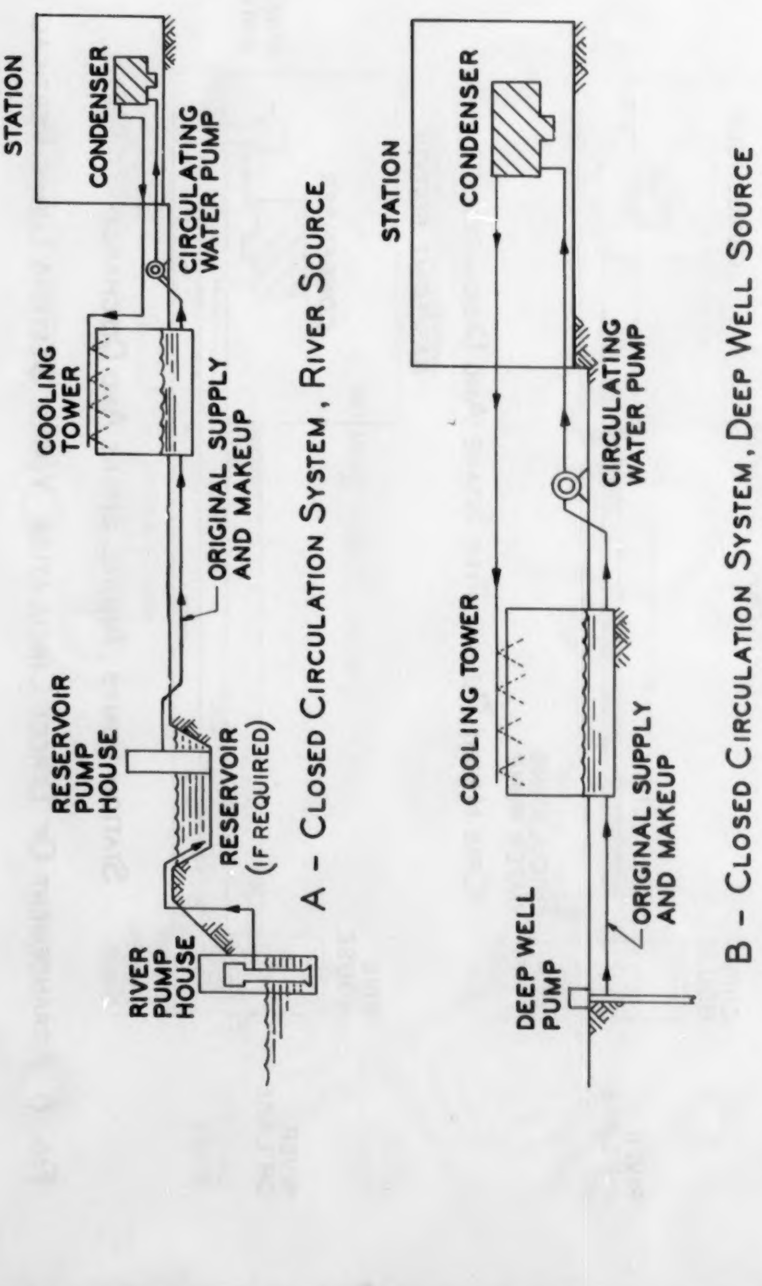


FIG. 7 ARRANGEMENT OF CLOSED CIRCULATION WATER SYSTEMS

Comparison of Cooling Towers, Spray Ponds and Reservoirs

Mention has been made of cooling towers, spray ponds and reservoirs used in closed circulation systems, and each has its proper application.

Cooling towers require the least amount of space for cooling purposes, and are therefore desirable where space is a major consideration. Maximum cooling is provided through mechanical evaporation, with minimum loss of water to the atmosphere.

Spray ponds can be used where considerably more space is available for the purpose. Cooling is a combination of mechanical and surface evaporation, and water loss is higher than for cooling towers.

Reservoirs or artificial lakes provide excellent cooling where inlet and outlet can be separated sufficiently for surface evaporation to provide the necessary cooling, and provide a good solution to the cooling problem provided either that sufficient acreage can be obtained at low cost to create an independent reservoir or that a reservoir or artificial lake is available.

Relationship of Civil Engineering to Station Water Supply

Development of water supply for thermal power stations is a combined mechanical and civil engineering function. From the civil engineers' standpoint, some hydrographic and hydraulic studies may be involved and reservoirs and dams are sometimes required, but the great bulk of the civil engineering is structural work. The extent of this work in developing and delivering the water supply and with reference to main building substructure depends to a great extent on whether the station has:

1. A river source with direct circulation.
2. A lake source with direct circulation.
3. Any closed circulation system.

For direct circulation river stations, the structural design and field construction for main building substructure work, for crib house, circulating water lines and discharge may have to provide for large fluctuations in river level from extreme low water to flood stages, and fairly extensive river bank protection may be involved.

For direct circulation lake stations, water variations are usually minor and have little bearing on main building substructure work. Wave action may require special treatment of crib houses and discharge structures, and breakwater or similar work may be necessary.

For closed circulation stations, those with river sources normally must have river pump houses designed for wide variations in river levels.

Dams, reservoirs, flumes and cooling tower or spray pond basins may be required. Mainbuilding substructure work, however, usually is not affected by the water source.

Minimizing the recirculation of intake and discharge water is an economic "must" for all direct circulation stations, and for closed circulation stations that have intake from, and discharge to, man-made lakes or ponds. Even a <u>single degree reduction</u> in cooling water temperature represents significant savings, which is well illustrated by a recent study made for an 800,000 kw midwestern station. This plant has direct circulation from a river source, and the addition of new units has created a serious recirculation problem,

thereby raising the question of relocating the present discharge point farther downstream. Analysis indicated that, for the fuel costs and capability charges applicable to this station, a $30,000 saving per year could be achieved for one degree reduction in cooling water temperature. The cost of the relocated discharge facilities must then be deducted from this gross saving to arrive at the net saving.

Each station, naturally, has its own optimum location of intake and discharge. This depends, among other considerations, on size, shape and depth of river or lake, intensity and variation of current, temperatures of the source water, direction and diffusion of discharge, and fuel costs and capability charges. And, as indicated for the example cited, optimum location for the original station may change as new units are added.

Since the direct circulation river station ordinarily requires a maximum of civil and structural design, the problems related to this type of station are discussed in some detail in the following paragraphs; for closed circulation stations design and construction are similar but normally less involved.

Selection of Pipe, Flumes or Tunnels for Circulating Water Intake and Discharge

A major decision which must be made in the early planning stages, and which involves considerable civil and structural, as well as mechanical, engineering analysis is whether to use pipe (steel or concrete), flumes, tunnels, or a combination of them, for intake and discharge lines. The choice of one or more must be determined for each job by considerations of site, initial and ultimate economy, and adaptibility for future expansion.

Location of the circulating water pumps is closely related to the selection of the most suitable system. If the pumps are in the crib house, the intake line between crib house and condenser is under pump discharge pressure and the line must be designed accordingly. If the pumps are in the station, intake between crib house and pumps is only under the pressure of the river or lake head.

In recent years the trend has been to use pipe for the intake line, with the circulating water pumps in the crib house, as this combination tends to reduce costs in several ways:

1. The pipe is usually less expensive than a comparable size concrete tunnel.
2. The pipe can be installed close to, or even above, ground surface, thus drastically cutting excavation requirements.
3. Pipe size need only be large enough for the individual unit, as additional lines for future units are relatively simple to install.

Pipe intake may also be used with the circulating water pumps located in the station, especially where the line has to provide for only one unit.

Tunnels are often an economical solution for the intake where required capacity is large, or where all units of a plant are installed at very nearly the same time, and where the circulating water pumps are located in the station. A disadvantage of tunnels is that they have to be installed quite deep and even the installation for the first unit may require sizing for the ultimate plant size, thus involving considerable initial capital expenditure, and necessary amortization, for future capacity. Further, even the best estimates of future

requirements often prove to have been too low when new units are added, and revamping the tunnel system is a considerable expense.

Flumes may be used for intake where the circulating water pumps are in the station so that flow is not under pressure. Such flumes may be merely dredged channels, or may be fairly elaborate structures with sheet piling walls. An advantage of flumes is the relative ease of increasing capacity, since these structures are usually in the open. For this same reason, however, they are somewhat of a maintenance problem, and may also require bridges or partial cover for purposes of plant access.

For discharge lines, the use of pipe is increasing, for the same reasons favoring their use for intake lines. Corrugated steel pipe appears to offer interesting possibilities for this purpose: for a recent addition to a large midwestern station, for example, analysis showed that the initial installed cost of a 10 ft. diameter corrugated steel pipe discharge line was only one-third the cost of a comparable reinforced concrete pipe line. Since the life expectancy of the corrugated steel pipe, based on performance records for other uses, appeared to be ample, the corrugated pipe was selected.

Tunnels and flumes, or combinations of them, are more often used for discharge lines than for intake purposes, especially for larger stations. They are frequently installed in combination with pipe intake lines, as will be shown in two examples later in this paper.

Design of pipes, tunnels and flumes, whether for intake or discharge, is an extremely varied and challenging civil and structural job, both in designing for the necessary hydraulic features, including uplift effects on the various structures, and in the layout and construction planning often required to install this phase of the work.

Design and Construction Features of Crib Houses

The crib house is the start of the water intake system. This structure has a trash rack, consisting of vertical bars, at the outside face to remove fish, plant life and other sizable debris, and inside are traveling screens to remove finer material. Where debris is especially heavy there may also be a separate mechanically raked bar screen between the trash rack and the traveling screen. Floating booms are usually located a short distance ahead of the crib house to prevent damage and clogging of the bar grills by large floating debris such as trees or logs. Mechanical or electrical fish screens may also be located just outside the trash rack to eliminate small fish that would pass through the bar grills and clog the traveling screens. For stations where freezing is a problem, an ice melting line using condenser discharge is run near the front of the crib.

The chlorine room is also normally located at the crib house, both for ease in adding chlorine to the circulating water and for increased safety for plant personnel by isolating this always potentially hazardous operation from the plant proper. The chlorine dosage is used to control algae growth which would otherwise seriously foul condenser tubes.

Crib houses are ordinarily built of reinforced concrete of conventional design other than necessary provisions for pressure and uplift due to high water levels. Customarily there are at least two traveling screens per crib in adjacent compartments, and the design must allow for one compartment at a time to be dewatered for working on the screens. The maximum water level at which dewatering is permissible is chosen from river hydrographs.

Construction of river crib houses usually requires steel sheet piling cofferdams or earth dikes, although in some cases the cribs have been designed as caissons, with a cutting edge constructed above water and then sunk, and additional lifts added as the inside area is excavated. Crib houses have also been constructed of steel sheet piling, with reinforced concrete floors for equipment, to reduce costs. Quite recently some crib houses have been designed and built as the base portion of concrete chimneys.

Main Building Substructure Design for Direct Circulation River Stations

Design and construction of the main building substructure for direct circulation river stations must include provisions for at least the following items in addition to regular building design requirements:

1. Foundation bearing levels may have to be carried low to allow for river level variations.
2. Basement floor construction must be designed for uplift due to high water, and the entire substructure checked for flotation at high water during the construction period when boiler and turbine loads are not yet in place.
3. Foundation walls must be carried above high water level and designed for the resultant pressures. Design must also provide for watertight construction to this level.
4. Cofferdams and dewatering equipment may be required in order to install substructure work.

Examples of Direct Circulation River Stations

Examples of direct circulation river stations are, of course, legion—but two have been selected as shown in the illustrations of Figs. 8 and 9 as being rather interesting.

Fig. 8 shows the plan and section for two of four units of a 475,000 kw station located on the Ohio River in Ohio. The latest unit for this station is presently nearing completion. Variation between high and low water is 73 feet and the station is designed to be floodproof to an elevation 5 feet above extreme high water of record.

The station has two reinforced concrete crib houses, each furnishing water for two units. The lower portions were constructed as caissons which were sunk through sand islands built in the river; the upper portions are rectangular. Each crib has two compartments, one for each unit. Screening arrangements are very complete because of large quantities of debris: at the front of each compartment is a trash rack with a mechanically operated rake for cleaning; behind the trash rack is a mechanically cleaned bar screen; and this is followed by a traveling screen.

Four circulating water pumps, two for each unit, are located in a watertight room in each crib, and supply the condensers through 60 inch steel pipe. Water treating facilities are in the crib house area above the main floor.

The condenser for each unit is located in an individual circular concrete condenser well supported on piles. The floor of each well is 67 feet below turbine room main floor to permit dropping the condenser so that the circulating water supply is in a direct horizontal line from the circulating water

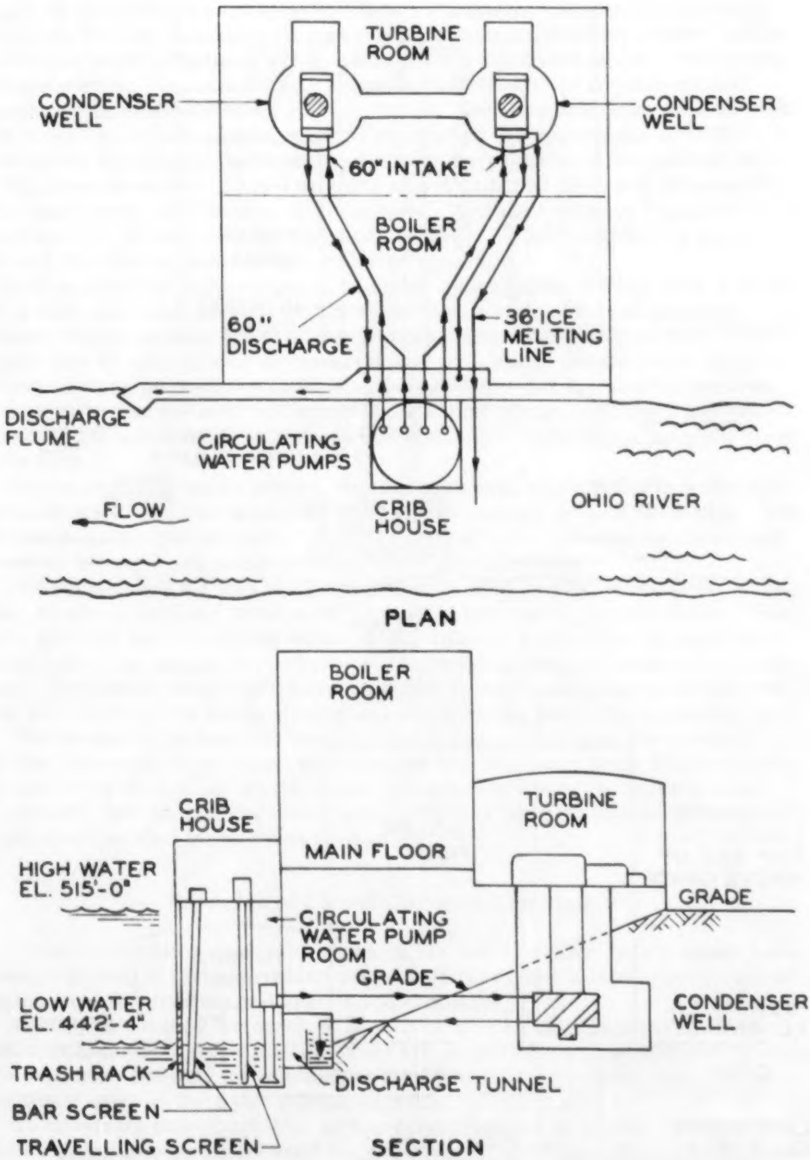


FIG. 8 DIRECT CIRCULATION SUPPLY FOR 475,000 KW RIVER STATION WITH CIRCULAR CONDENSING WELLS

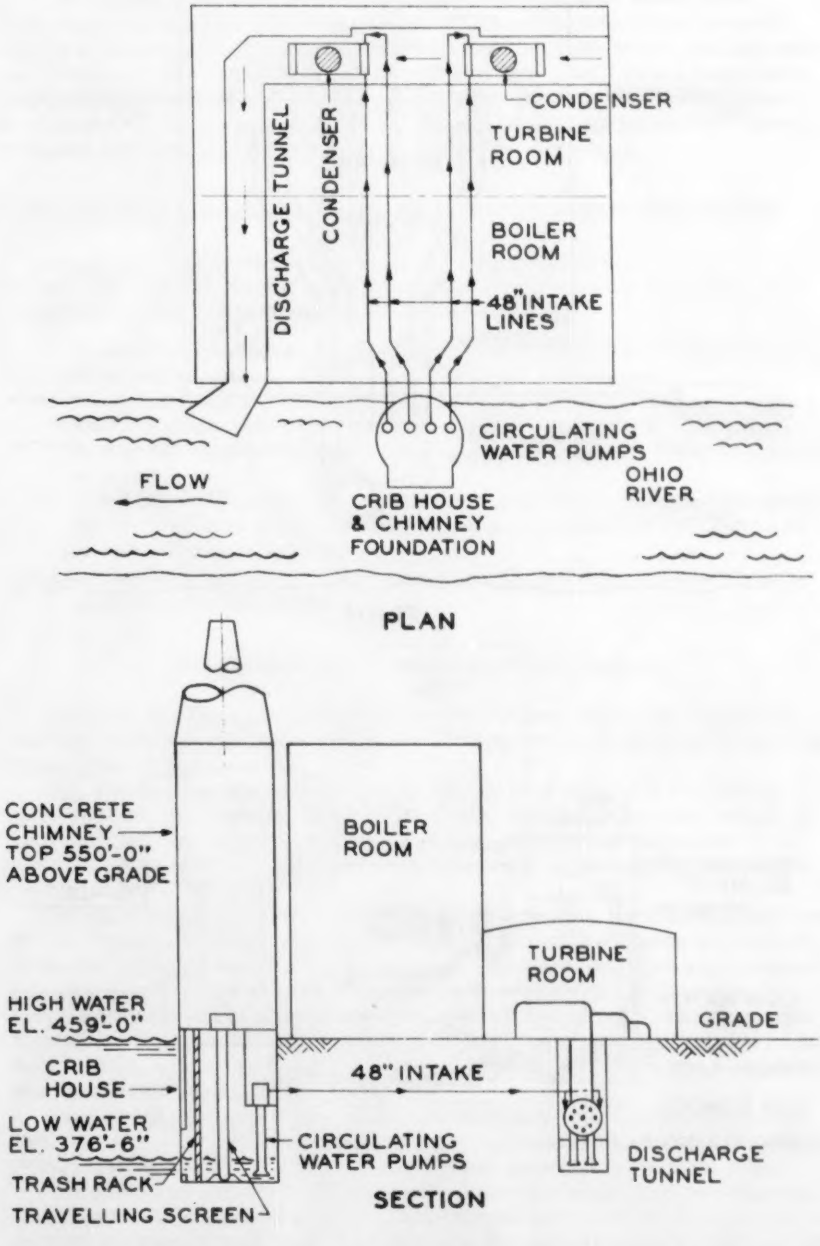


FIG. 9 DIRECT CIRCULATION CONDENSING WATER SUPPLY FOR 600,000 KW RIVER STATION WITH CRIB UNDER CHIMNEY

pumps, thereby keeping pumping costs to a minimum. Condenser discharge is through 60 inch steel pipe emptying into a concrete discharge tunnel which discharges about 200 feet downstream of Unit 1 and 2 crib house. Thirty-six inch ice melting lines are cross connected to each pair of condensers and brought out through the crib houses to extend along the upstream side of each. Both boiler room and turbine room of the station are located out over the river bank, which again reduces the distance for pumping of circulating water.

Fig. 9 pictures two 150,000 kw units of a 4 unit, 600,000 kw station on the Ohio River near the southern tip of Indiana. Variation between high and low water here is 83 feet, and the station is designed to be floodproof to an elevation 6 feet above extreme high water of record.

This station has two reinforced concrete crib houses, one for each 2 units, but in this case each crib forms the foundation for a reinforced concrete chimney which extends 550 feet above grade. The crib house-chimney foundations are 68 feet outside diameter, with 4 foot walls, and the front portion of each is squared off for screen chambers. There are 4 traveling screens in each crib, two per unit. Thirty inch steel pipe ice melting lines are embedded in the walls between screens and discharge warm water near the front of the crib.

Four circulating water pumps, two for each unit, are located in watertight rooms in each crib and supply the condensers through 48 inch steel pipe. The crib houses also contain motor control centers, water treating facilities and chemical storage, and demineralized water storage tanks.

The condensers for this station are also located in pits, rectangular in this case, in which the floor level is 65 feet below turbine room main floor. This again permits the circulating water supply lines to extend in a straight horizontal line from pumps to condensers, thus holding pumping costs to a minimum. Condenser discharge is directed into a concrete discharge tunnel running full length of the turbine room and immediately below the condenser pits.

This tunnel turns near the start of Unit 1 and runs across the width of turbine room and boiler room to discharge into the river some 200 feet downstream of the Unit 1 and 2 crib house. Both boiler room and turbine room are located just back of the river bank, with only the crib house-chimney foundations located in the river bank.

Examples of Closed Circulation Stations

Closed circulation systems represent, as noted earlier, only a small percentage of total circulating water use—but they require a large percentage of engineering imagination and analysis to conceive.

Variety is not only the spice of life—it is also an apt description of the different combinations of methods used for closed circulation systems of various stations. Not only do combinations vary from station to station—but for additional units of the same station as well.

To illustrate this point, Fig. 10 has been prepared to show a variety of closed circulation systems used for a number of stations. Particular attention is drawn to Stations A, C and D, where changes in closed circulation methods were required for successive units.

WATER SUPPLY TO THERMAL
POWER PLANTS

STATION A. KANSAS - 32,000 KW, 3 UNITS
Units 1 and 2, direct intake from deep wells, discharge not reused. Unit 3, cooling tower with deep well make-up, as well capacity not sufficient for 3 units on direct circulation.

STATION B. KENTUCKY - 100,000 KW, 1 UNIT
Station on plateau 100 feet above highest water level of 123,000 acre-ft. reservoir formed by dam which is part of 30 year hydroelectric development. Cooling tower, with make-up from lake, less expensive than direct circulation from lake, because of average 150 foot pump lift and 60 foot variation in reservoir level resulting from wide seasonal fluctuation in run-off from drainage area.

STATION C. LOUISIANA - 145,000 KW, 5 UNITS
Units 1 and 4, cooling towers. Units 2 and 3, spray ponds. Thirty acre artificial lake then built with earth dikes to increase circulation length for spray pond discharge. Unit 5, now under construction, will have new spray heads at one end of lake for combination mechanical and natural surface cooling.

STATION D. LOUISIANA - 200,000 KW, 6 UNITS
Units 1 to 3 exhausted direct circulation capacity of one bayou. 500 feet of spray headers installed on bayou bank for Unit 4. Low level dike built on second bayou for recently completed Unit 5, to create 620 acre lake for natural surface cooling. Unit 5 discharge to 2 mile open flume from station to lake. Lake discharge back to original bayou for Unit 5 intake. New Unit 6 and future Unit 7 will also use lake circulation.

STATION E. OKLAHOMA - 66,000 KW, 1 UNIT
3.6 million gallon reservoir built for storage of make-up to cooling tower, with supply from two artesian wells and one deep well.

STATION F. OKLAHOMA - 260,000 KW, 6 UNITS
Two earth dams built across loop of low-flow river created 200 acre horseshoe-shaped lake for natural surface cooling. New channel dredged for river bypass. Station at open end of horseshoe, intake from one leg, discharge to other, 2 miles of circulation between. River make-up to lake.

STATION G. TEXAS - 166,000 KW, 2 UNITS
One thousand foot square, 67 million gallon reservoir built with Unit 1 for storage of make-up to cooling towers. Reservoir supply from irrigation district canal taking water from Rio Grande river. Unit 2 now under construction.

FIG. 10 - CLOSED CIRCULATION CONDENSER COOLING WATER SYSTEMS FOR 7 POWER STATIONS

Water Supply to Vermilion Power Station

An outstanding example of solving the water supply problem for a new thermal power plant located in an area of low available water is the Vermilion Power Station of Illinois Power Company. Creation of a 120-acre artificial lake was the key element for this plant which is located on a branch of the Vermilion River approximately 10 miles northwest of Danville in Central Illinois and near the Indiana state line. This lake supplies all water required for both circulating water and station service water systems, including boiler make-up.

Vermilion Station, as shown in the aerial view of Fig. 11 consists of a main building, water pumping and treating structures, coal handling facilities, 69 kv and 132 kv switchyards—and the 120-acre reservoir which has a capacity of 700 million gallons. The plant, which is basically an indoor type at grade level, is located on a plateau 130 feet above river level and 20 feet above maximum reservoir level. Unit 1 is 75,000 kw with a 525,000 pound per hour semi-outdoor boiler, and went into operation in 1955. Unit 2 is 100,000 kw with a 713,000 pound semi-outdoor boiler and went on the line in 1956.

The Problem and the Answer

The Danville area is a heavy load distribution center for Illinois Power Company's system. When it was decided to build a station to meet this load, the choice narrowed to a cooling tower station near Danville or a river station on the Wabash River in Indiana. Economic studies indicated the cooling tower station to be more desirable, even though extensive surveys of a number of sites in the Danville area showed the only available source of water was the middle fork of the Vermilion River—which has a very low minimum flow.

Fig. 11. Earth Dam 75 ft. High Closes Mouth of Ravine to Impound 120 Acre Lake for Vermilion Power Station Water Supply System. Full 2500 ft. Length of Dam and Dikes Shown Before Start of Water Storage.

Two solutions to this problem were considered:

1. A dam could be built across the river with provision for controlling flow.
2. An artificial lake could be constructed.

The first solution was rejected because a river dam would be costly to construct, would involve extensive maintenance and control, and would require acquisition of all land flooded by back water.

The many deep natural ravines in the area made the artificial lake the better solution, as any one of the ravines could be dammed at relatively little cost and water pumped in from the river during periods of high stream flow.

Design basis for the artificial lake was a station capacity of 275,000 kw operating at 60 per cent load factor for 120 days without inflow, this period exceeding the longest dry spell on record. Analysis of evaporation, seepage, siltage and make-up water requirements, as shown in Fig. 12 indicated the necessity of approximately 2400 acre-feet storage volume. This dictated the 120-acre surface area and 50 foot maximum depth of reservoir. The reservoir itself has about one square mile of drainage area, but this was not directly included in the design—rather, run-off from this source was considered as an additional factor of safety.

Basic of Demand: 275,000 kw and 120 days without inflow

Load Factor	60 %
Tower Evaporation	1,614 gpm
Windage Loss 0.2%	386 gpm
Tower Blowdown	224 gpm
Reservoir Evaporation, 0.2" per day	455 gpm
Siltage	8 gpm
Seepage	1,200 gpm
Station Steam Make-Up	30 gpm
Ash Sluice Water	178 gpm
Total	4,095 gpm
Acre Feet Required	2,160
10% Margin	216
Reservoir Acre Feet Total	2,376

Fig. 12—Station Water Requirements for Vermilion Reservoir Design

Since the station went into operation, continuous inspections have been made and records kept of seepage and other losses, and it is interesting to note that all have been below design assumptions. River pumping has accordingly been less than anticipated. To date a drought year has not occurred.

Water Supply Layout

The entire water system layout is well illustrated by Figs. 13 and 14.(5) Briefly, a river pump house takes suction from the river and lifts the water

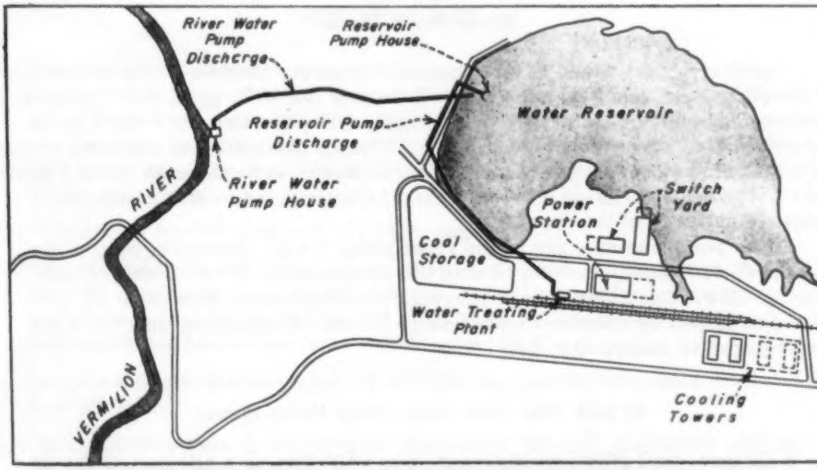


FIG.13 Artificial 120 Acre Water Reservoir Provides For Ultimate Capacity of 275,000 kw for Vermilion Power Station

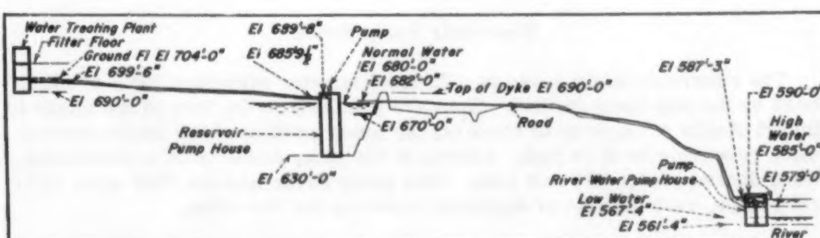


FIG.14 Profile of Water Supply System For Vermilion Power Station

120 feet through 2200 feet of 20 inch diameter steel pipe to the reservoir. A reservoir pump house lifts the water an additional 20 feet through a 14 inch diameter steel pipe to the water treating plant. From here the water is channeled as make-up to the circulating water system, for bearing cooling and for boiler feed make-up.

Reservoir and Dam

The storage reservoir was formed by building an earth dam across the mouth of one ravine right adjacent to the plant, this ravine having been chosen as adequate from among several ravine sites that had been surveyed and plotted. The deep portion of the dam is about 400 feet long and about 75 feet high, with dikes extending to a total length of 2500 feet. Suitable compacted fill material to form the dam was found in the immediate area. Inspection wells were installed in the dam to permit continual checking on ground water levels.

River Pump House

The river pump house is a rectangular concrete structure with double intake portals screened by bar grills. It houses two 4500-gpm, 200-foot head vertical pumps in a watertight pump room, with provision for a third pump should future expansion so require. Each pump has sufficient capacity to supply make-up water for two units. Vertical pumps were selected since a possible water level variation of 47 feet must be anticipated to utilize maximum storage capacity of the reservoir.

River pump controls are at the river pump house. However, pumps are equipped with safety shutoffs to stop the pumps in the event of loss of discharge flow. One pump will be operated whenever river flow is 20 cfs and two pumps will be operated when flow is 30 cfs. A minimum flow of 10 cfs is required to sustain fish life.

20 Inch Pipe Line from River Pump House

A 20 inch steel pipe line snakes its ways 120 feet up a hill and 2200 feet between trees and across gullies to carry the river pump discharge to the reservoir. The line lies exposed on the ground for most of its length, and is provided with necessary expansion loops and anchors.

Reservoir Pump House

The reservoir pump house is a 22 foot diameter structure 59' - 8" high, built by the slip form method. Slots are provided on the face of the intake to insert double screens or to blank off the lower portion of the intake opening when reservoir level is high. Access to the pump house is by a steel beam, wood decked bridge 185 feet long. This pump house has two 2500-gpm vertical pumps, each capable of supplying make-up for two units.

Circulating Water Pumps and Piping

Circulating water pumps for both units are of the horizontal outdoor type, located on a concrete apron just outside the boiler room. Pumps for Unit 1 are two 26,000 gpm, and those for Unit 2 are two 35,000 gpm.

Supply to the condensers is through 54 inch (Unit 1) and 66 inch (Unit 2) steel pipe suspended below the main floor of the station, with steel pipe discharge lines below the ground floor. A 54 inch steel pipe discharge line is used between Unit 1 condenser and cooling tower, and a separate 66 inch steel pipe discharge between Unit 2 condenser and cooling tower. Suction from both cooling towers is combined in a single 78 inch concrete pipe line up to a junction manhole, where separate 54 inch and 66 inch concrete pipe connect back to the circulating water pumps.

ACKNOWLEDGEMENTS

The assistance of Mr. A. M. Levy of Sargent & Lundy in the preparation of this paper is greatly appreciated.

BIBLIOGRAPHY

1. Data on per capita water consumption is based on figures given in the May, 1957, Journal of the American Water Works Association, reporting on a 1955 survey made by the Association. Population figures for cities are from the same source, except those for Los Angeles and New York City which are from the 1958 World Almanac published by the New York World-Telegram.

2. "Electrical World", January 27, 1958, page 105.

3. "On the Water Front", The League of Women Voters of the United States, page 5. Also see "Availability of Water in the United States with Special Reference to Industrial Needs by 1980", by D. R. Woodward, Industrial College of the Armed Services, Washington, D. C.

4. Sargent & Lundy statistics for all of their stations for the years 1945 through 1957.

5. These illustrations by courtesy of "Electrical World", originally used for an article, "Made-Lake Beats Cooling Problem" by F. V. Smith, Sargent & Lundy, and R. L. Martin, Illinois Power Company, which appeared in the May 16, 1955, issue of "Electrical World".

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1859 is identified as 1859 (HY 7) which indicates that the paper is contained in the seventh issue of the Journal of the Hydraulics Division during 1958.

VOLUME 83 (1957)

DECEMBER: 1449(HY6), 1450(HY6), 1451(HY6), 1452(HY6), 1453(HY6), 1454(HY6), 1455(HY6), 1456(HY6)[c], 1457(PO6), 1458(PO6), 1459(PO6), 1460(PO6)[c], 1461(SA6), 1462(SA6), 1463(SA6), 1464(SA6), 1465(SA6), 1466(SA6)[c], 1467(AT2), 1468(AT2), 1469(AT2), 1470(AT2), 1471(AT2), 1472(AT2), 1473(AT2), 1474(AT2), 1475(AT2), 1476(AT2), 1477(AT2), 1478(AT2), 1479(AT2), 1480(AT2), 1481(AT2), 1482(AT2), 1483(AT2), 1484(AT2), 1485(AT2)[c], 1486(BD2), 1487(BD2), 1488(PO6), 1489(PO6), 1490(BD2), 1491(BD2), 1492(HY6), 1493(BD2).

VOLUME 84 (1958)

JANUARY: 1494(EM1), 1495(EM1), 1496(EM1), 1497(IR1), 1498(IR1), 1499(IR1), 1500(IR1), 1501(IR1), 1502 (IR1), 1503(IR1), 1504(IR1), 1505(IR1), 1506(IR1), 1507(IR1), 1508(ST1), 1509(ST1), 1510(ST1), 1511(ST1), 1512(ST1), 1513(WW1), 1514(WW1), 1515(WW1), 1516(WW1), 1517(WW1), 1518(WW1), 1519(ST1), 1520 (EM1)[c], 1521(IR1)[c], 1522(ST1)[c], 1523(WW1)[c], 1524(HW1), 1525(HW1), 1526(HW1)[c], 1527(HW1).

FEBRUARY: 1528(HY1), 1529(PO1), 1530(HY1), 1531(HY1), 1532(HY1), 1533(SA1), 1534(SA1), 1535(SM1), 1536(SM1), 1537(SM1), 1538(PO1)[c], 1539(SA1), 1540(SA1), 1541(SA1), 1542(SA1), 1543(SA1), 1544(SM1), 1545(SM1), 1546(SM1), 1547(SM1), 1548(SM1), 1549(SM1), 1550(SM1), 1551(SM1), 1552(SM1), 1553(PO1), 1554(PO1), 1555(PO1), 1556(PO1), 1557(SA1)[c], 1558(HY1)[c], 1559(SM1)[c].

MARCH: 1560(ST2), 1561(ST2), 1562(ST2), 1563(ST2), 1564(ST2), 1565(ST2), 1566(ST2), 1567(ST2), 1568 (WW2), 1569(WW2), 1570(WW2), 1571(WW2), 1572(WW2), 1573(WW2), 1574(PL1), 1575(PL1), 1576(ST2)[c] 1577(PL1), 1578(PL1)[c], 1579(WW2)[c].

APRIL: 1580(EM2), 1581(EM2), 1582(HY2), 1583(HY2), 1584(HY2), 1585(HY2), 1586(HY2), 1587(HY2), 1588 (HY2), 1589(IR2), 1590(IR2), 1591(IR2), 1592(SA2), 1593(SU1), 1594(SU1), 1595(SU1), 1596(EM2), 1597(PO2), 1598(PO2), 1599(PO2), 1600(PO2), 1601(PO2), 1602(PO2), 1603(HY2), 1604(EM2), 1605(SU1)[c], 1606(SA2), 1607(SA2), 1608(SA2), 1609(SA2), 1610(SA2), 1611(SA2), 1612(SA2), 1613(SA2), 1614(SA2)[c], 1615(IR2)[c], 1616 (HY2)[c], 1617(SU1), 1618(PO2)[c], 1619(EM2)[c], 1620(CP1).

MAY: 1621(HW2), 1622(HW2), 1623(HW2), 1624(HW2), 1625(HW2), 1626(HW2), 1627(HW2), 1628(HW2), 1629 (ST3), 1630(ST3), 1631(ST3), 1632(ST3), 1633(ST3), 1634(ST3), 1635(ST3), 1636(ST3), 1637(ST3), 1638(ST3), 1639(WW3), 1640(WW3), 1641(WW3), 1642(WW3), 1643(WW3), 1644(WW3), 1645(SM2), 1646(SM2), 1647 (SM2), 1648(SM2), 1649(SM2), 1650(SM2), 1651(HW2), 1652(HW2)[c], 1653(WW3)[c], 1654(SM2), 1655(SM2), 1656(ST3)[c], 1657(SM2)[c].

JUNE: 1658(AT1), 1659(AT1), 1660(HY3), 1661(HY3), 1662(HY3), 1663(HY3), 1664(HY3), 1665(SA3), 1666 (PL2), 1667(PL2), 1668(PL2), 1669(AT1), 1670(PO3), 1671(PO3), 1672(PO3), 1673(PL2), 1674(PL2), 1675 (PO3), 1676(PO3), 1677(SA3), 1678(SA3), 1679(SA3), 1680(SA3), 1681(SA3), 1682(SA3), 1683(PO3), 1684 (HY3), 1685(SA3), 1686(SA3), 1687(PO3), 1688(SA3)[c], 1689(PO3)[c], 1690(HY3)[c], 1691(PL2)[c].

JULY: 1692(EM3), 1693(EM3), 1694(ST4), 1695(ST4), 1696(ST4), 1697(SU2), 1698(SU2), 1699(SU2), 1700(SU2), 1701(SA4), 1702(SA4), 1703(SA4), 1704(SA4), 1705(SA4), 1706(EM3), 1707(ST4), 1708(ST4), 1709(ST4), 1710 (ST4), 1711(ST4), 1712(ST4), 1713(SU2), 1714(SA4), 1715(SA4), 1716(SU2), 1717(SA4), 1718(EM3), 1719 (EM3), 1720(SU2), 1721(ST4)[c], 1722(ST4), 1723(ST4), 1724(EM3)[c].

AUGUST: 1725(HY4), 1726(HY4), 1727(SM3), 1728(SM3), 1729(SM3), 1730(SM3), 1731(SM3), 1732(SM3), 1733 (PO4), 1734(PO4), 1735(PO4), 1736(PO4), 1737(PO4), 1738(PO4), 1739(PO4), 1740(PO4), 1741(PO4), 1742 (PO4), 1743(PO4), 1744(PO4), 1745(PO4), 1746(PO4), 1747(PO4), 1748(PO4), 1749(PO4).

SEPTEMBER: 1750(IR3), 1751(IR3), 1752(IR3), 1753(IR3), 1754(IR3), 1755(ST5), 1756(ST5), 1757(ST5), 1758(ST5), 1759(ST5), 1760(ST5), 1761(ST5), 1762(ST5), 1763(ST5), 1764(ST5), 1765(WW4), 1766(WW4), 1767(WW4), 1768(WW4), 1769(WW4), 1770(WW4), 1771(WW4), 1772(WW4), 1773(WW4), 1774(IR3), 1775 (IR3), 1776(SA5), 1777(SA5), 1778(SA5), 1779(SA5), 1780(SA5), 1781(WW4), 1782(SA5), 1783(SA5), 1784 (IR3)[c], 1785(WW4)[c], 1786(SA5)[c], 1787(ST5)[c], 1788(IR3), 1789(WW4).

OCTOBER: 1790(EM4), 1791(EM4), 1792(EM4), 1793(EM4), 1794(EM4), 1795(HW3), 1796(HW3), 1797(HW3), 1798(HW3), 1799(HW3), 1800(HW3), 1801(HW3), 1802(HW3), 1803(HW3), 1804(HW3), 1805(HW3), 1806 (HY5), 1807(HY5), 1808(HY5), 1809(HY5), 1810(HY5), 1811(HY5), 1812(SM4), 1813(SM4), 1814(ST6), 1815 (ST6), 1816(ST6), 1817(ST6), 1818(ST6), 1819(ST6), 1820(ST6), 1821(ST6), 1822(EM4), 1823(PO5), 1824 (SM4), 1825(SM4), 1826(SM4), 1827(ST6)[c], 1828(SM4)[c], 1829(HW3)[c], 1830(PO5)[c], 1831(EM4)[c], 1832(HY5)[c]

NOVEMBER: 1833(HY6), 1834(HY6), 1835(SA6), 1836(ST7), 1837(ST7), 1838(ST7), 1839(ST7), 1840(ST7), 1841(ST7), 1842(SU3), 1843(SU3), 1844(SU3), 1845(SU3), 1846(SU3), 1847(SA6), 1848(SA6), 1849(SA6), 1850(SA6), 1851(SA6), 1852(SA6), 1853(SA6), 1854(ST7), 1855(SA6)[c], 1856(HY6)[c], 1857(ST7)[c], 1858 (SU3)[c].

DECEMBER: 1859(HY7), 1860(IR4), 1861(IR4), 1862(IR4), 1863(SM5), 1864(SM5), 1865(ST8), 1866(ST8), 1867 (ST8), 1868(PP1), 1869(PP1), 1870(PP1), 1871(PP1), 1872(PP1), 1873(WW5), 1874(WW5), 1875(WW5), 1876 (WW5), 1877(CP2), 1878(ST8), 1879(ST8), 1880(HY7)[c], 1881(SM5)[c], 1882(ST8)[c], 1883(PP1)[c], 1884(WW5)[c], 1885(CP2)[c], 1886(PO6), 1887(PO6), 1888(PO6), 1889(PO6), 1890(HY7), 1891(PP1).

c. Discussion of several papers, grouped by divisions.

AMERICAN SOCIETY OF CIVIL ENGINEERS

OFFICERS FOR 1959

PRESIDENT

FRANCIS S. FRIEL

VICE-PRESIDENTS

Term expires October, 1959:
WALDO G. BOWMAN
SAMUEL B. MORRIS

Term expires October, 1960:
PAUL L. HOLLAND
LLOYD D. KNAPP

DIRECTORS

Term expires October, 1959:
CLINTON D. HANOVER, Jr.
E. LELAND DURKEE
HOWARD F. PECKWORTH
FINLEY B. LAVERTY
WILLIAM J. HEDLEY
RANDLE B. ALEXANDER

Term expires October, 1960:
PHILIP C. RUTLEDGE
WESTON S. EVANS
TILTON E. SHELBURNE
CRAIG P. HAZELET
DONALD H. MATTERN
JOHN E. RINNE

Term expires October, 1961:
THOMAS S. FRATAR
EARL F. O'BRIEN
DANIEL B. VENTRES
CHARLES W. BRITZIUS
WAYNE G. O'HARRA
FRED H. RHODES, JR.
N. T. VEATCH

PAST PRESIDENTS
Members of the Board

MASON G. LOCKWOOD

LOUIS R. HOWSON

EXECUTIVE SECRETARY
WILLIAM H. WISELY

TREASURER
CHARLES E. TROUT

ASSISTANT SECRETARY
E. LAWRENCE CHANDLER

ASSISTANT TREASURER
ENOCH R. NEEDLES

PROCEEDINGS OF THE SOCIETY

HAROLD T. LARSEN
Manager of Technical Publications

PAUL A. PARISI
Editor of Technical Publications

MARVIN SCHECHTER
Assistant Editor of Technical Publications

COMMITTEE ON PUBLICATIONS

HOWARD F. PECKWORTH, *Chairman*

PHILIP C. RUTLEDGE, *Vice-Chairman*

E. LELAND DURKEE

CHARLES W. BRITZIUS

TILTON E. SHELBURNE

FRED H. RHODES, JR.